SPECIAL REPORT 92-6

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CRREL

Ship Icing Instrumentation

Michael R. Walsh, James S. Morse, Kurt V. Knuth and Dennis J. Lambert

April 1992

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U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

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Prepared for
U.S. NAVY DAVID TAYLOR SHIP RESEARCH AND DEVELOPMENT CENTER

PREFACE

This report was prepared by Michael R. Walsh, Mechanical Engineer, James S. Morse, Electronics Engineer, Kurt V. Knuth, Electronics Engineer, and Dennis J. Lambert, Mechanical Engineering Technician, Engineering and Measurement Services Office, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this study was provided by the U.S. Navy David Taylor Ship Research and Development Center (DTRC) under MPR N00167-90-MP-00223.

The authors wish to thank the following people for their contributions to this report: Lieutenant Commander Paul Longo and Dr. Charles C. Ryerson for their extensive reviews, Pamela Bosworth for typing the original manuscript, and Edward Perkins and Matthew Pacillo for illustrations. Also acknowledged are the people at DTRC who made this work possible. In addition, a special thanks goes to Captain Stanley Winslow and the crew of the USCGC *Midgett* who, through their generous help, greatly facilitated the Aleutian trial of the ship icing equipment.

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Ship Icing Instrumentation

MICHAEL R. WALSH, JAMES S. MORSE, KURT V. KNUTH, AND DENNIS J. LAMBERT

INTRODUCTION

Ship icing is a cold regions phenomenon that can be very detrimental to the readiness or operability of naval surface ships. Superstructure icing results in increased weight and a shifting of the center of gravity. If the center of gravity shifts above the metacenter of the ship, the weight of the ship will act against the center of buoyancy, capsizing it. Although this drastic situation is not common, other effects of ship icing, such as reduced speed and maneuverability, as well as severe limitations on deck operations and equipment damage, can easily reduce the functioning of a ship to the point of near inoperability. For these reasons, an understanding of the mechanics and meteorological factors of ship icing is crucial when ships are deployed in cold regions.

In 1988, the U.S. Navy's David Taylor Ship Research and Development Center (DTRC) contracted with CRREL to develop a ship icing model. To develop such a model, empirical data from actual ship cruises—such as spray fluxes, ice accretion on decks and bulkheads, video records of spray events and ambient temperature measurements—are needed. This report describes the instrumentation designed and constructed by CRREL to obtain these data, as well as its operation and maintenance. The objective was originally to prepare a manual to provide field personnel with enough information to understand the basic instrumentation and data acquisition functions involved, as well as to effectively install and operate this equipment.

Unfortunately, soon after the manual was prepared in draft form, some serious problems related to salt water were discovered on the USCG *Midgett* test cruise (see Ryerson and Longo [in press] for details). Most of the equipment, however, proved quite rugged and dependable during that 40-day cruise in rough water and adverse conditions. For this reason we have decided that publishing this information is still a useful enterprise. Many problems were successfully overcome and the majority of the components of the instrumentation worked well. Future icing research will benefit from our successes as well as our failures.

This report provides an overview of the theory and use of the instrumentation, information on instrumentation calibration and maintenance, and troubleshooting tips. A supplement is available (Walsh et al. 1991) that contains a suggested tool kit, assembly lists, software printouts and other useful information that is too bulky to include here.

GENERAL DESCRIPTION

The instrumentation described in this report consists of two separate systems: the Spray–Icing Unit (SIU) and the video system. The SIU (Fig. 1) is a stand-alone instrument, capable of obtaining data on spray fluxes impinging on the ship's structure during spray events and on ice accretion on either bulkheads or decking, monitoring ambient temperature, and performing several internal functions such as data acquisition, power monitoring and data storage. The SIU is bolted to sacrificial chairs (mounts) that are welded to the ship's deck. Major components are designed as modular units that are interchangeable and easily serviced. The main components of the SIU are the enclosure, the spray collector (horizontal or vertical), the ice accretion ranging arm and, inside the SIU, the accumulation tank, power sources and electronics. Power sources, both electrical and pneumatic, can be recharged below decks or, in the case of the batteries, on deck.

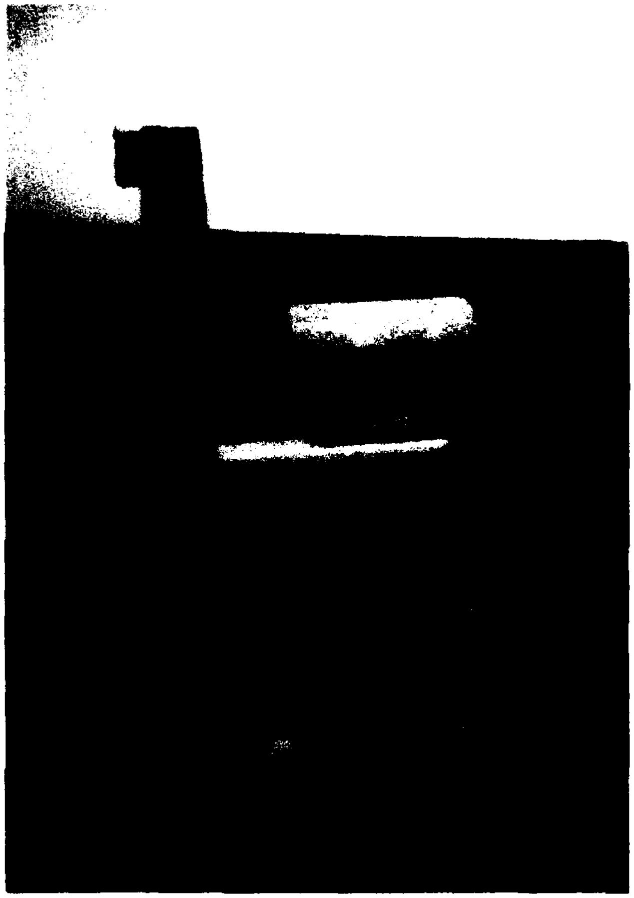
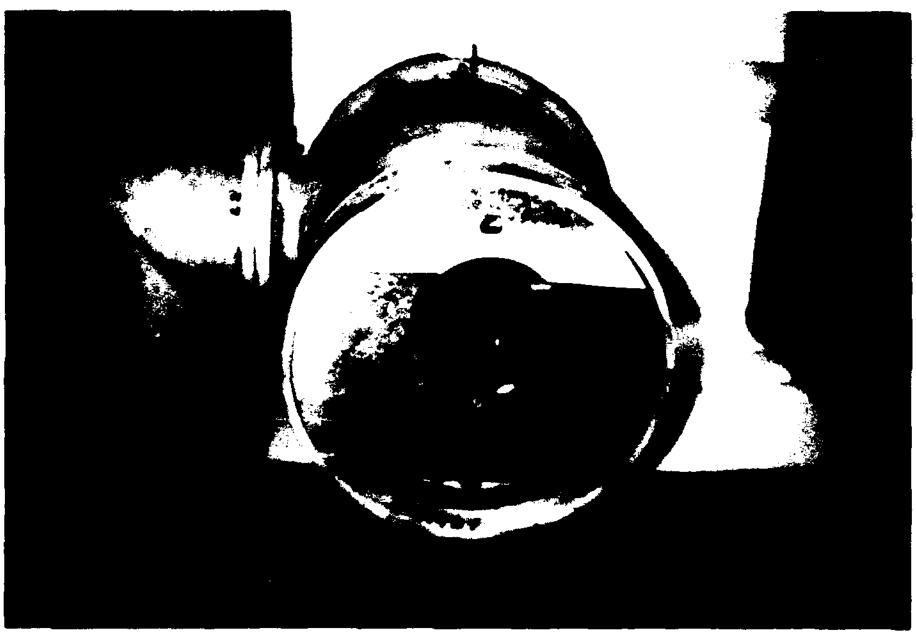
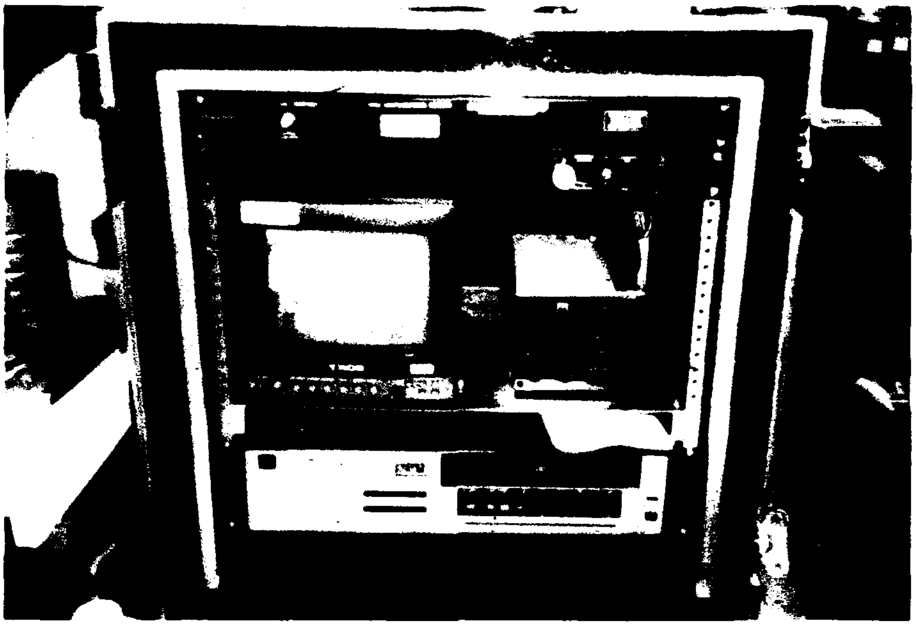


Figure 1. Spray–Icing Unit (SIU).



a. Camera Unit (CU).

Figure 2. Video system.



b. Camera Electronics Unit (CEU).

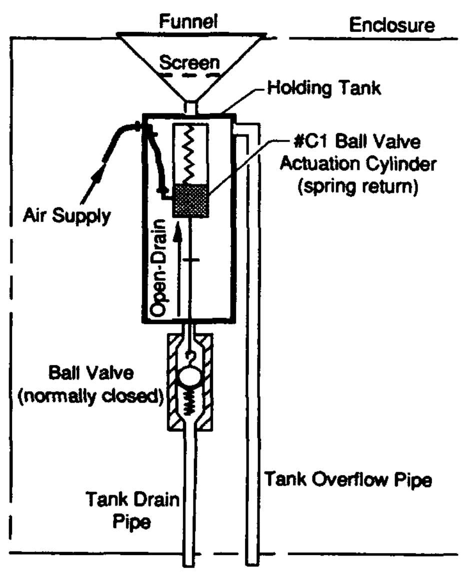
Figure 2 (cont'd).

The video system consists of two parts: the Camera Unit (CU) and the Camera Electronics Unit (CEU) (Fig. 2). The CU interfaces with and is powered by a cable that runs between the CEU and the CU. The CU is mounted to the deck in a way similar to the SIU, through a sacrificial mounting pad welded to the deck. The CEU contains a video recorder (VCR), a monitor, a camera power supply and a washer–wiper control. The VCR records image and time–date data only. The CEU is powered from the ship's line (120-V ac), thus requiring external cabling. The video system, together with the SIUs and the ship's meteorological and navigation data, provide all required model data.

THEORY OF OPERATION

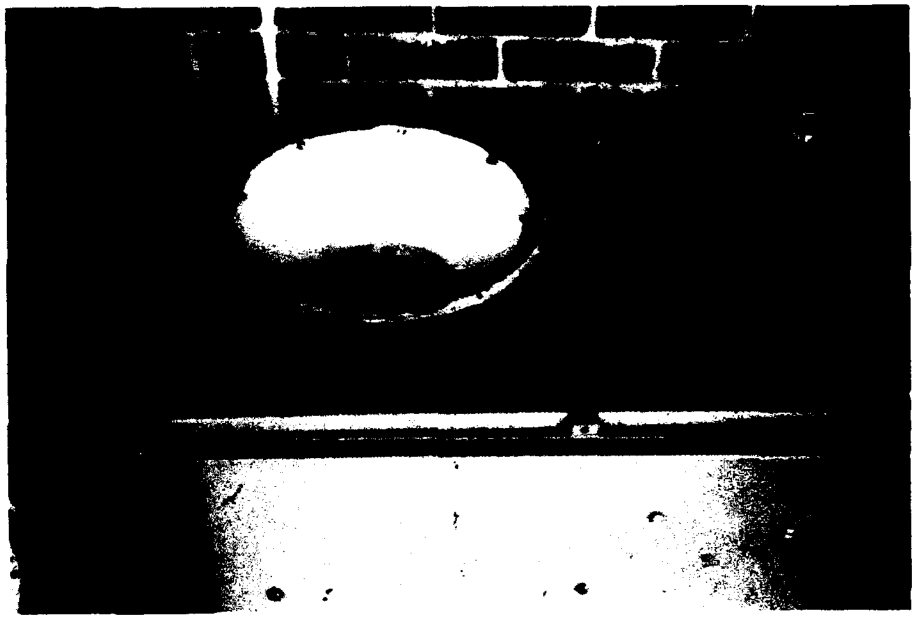
The two major components of the ship icing instrumentation collect different types of data. The spray–icing units collect quantitative data on icing, spray and temperature. The video system obtains qualitative data from which estimates of time and physical characteristics of spray events can be obtained. In addition, the video data can serve as a confirmation tool for the SIUs by correlating spray flux data to video images of corresponding spray events.

Spray flux and ice accretion thickness measurement are the two primary functions of the SIU. The instrumentation is designed to obtain flux data in either of two orientations: horizontal or vertical. The vertical collector is much like a commercial



a. Cutaway view.

Figure 3. Vertical spray collector.



b. View of collection area on SIU.

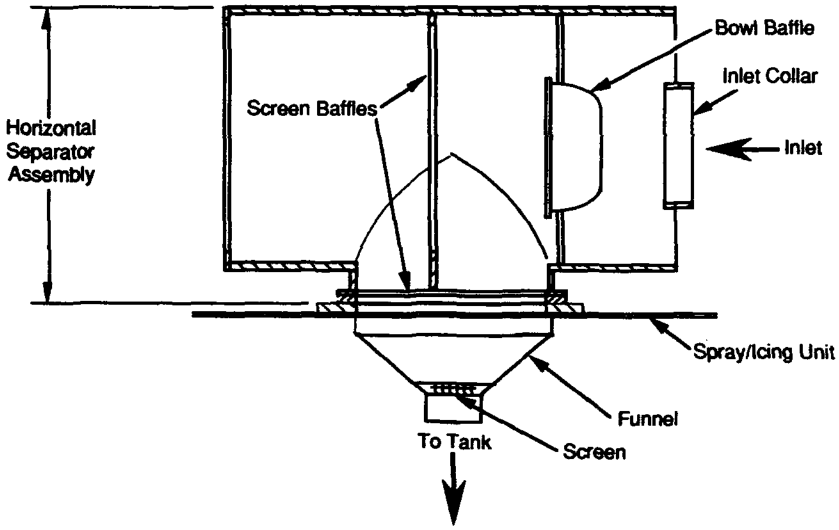
Figure 3 (cont'd). Vertical spray collector.

rain gauge and consists of a large funnel with an inclusive debris screen mounted on the top of the SIU enclosure (Fig. 3). The funnel drains into an 11.6-L collection tank that measures and automatically drains the collected water. The vertical collector's function is to gather the water from spray fluxes that would normally strike the deck. The vertical acquisition mode relies primarily on gravitational separation of the water droplets from the spray cloud. It assumes that vertical air currents are not of an order that would cause the formation of an air plug at the acquisition orifice, thus diverting and excluding spray from entering the funnel and holding tank. Various sized orifice plates can be attached to the inlet to regulate the acquisition area and thus the volume of water collected during spray events. Using a reducing orifice reduces the collection area, which must be calculated into the spray flux measurements when used.

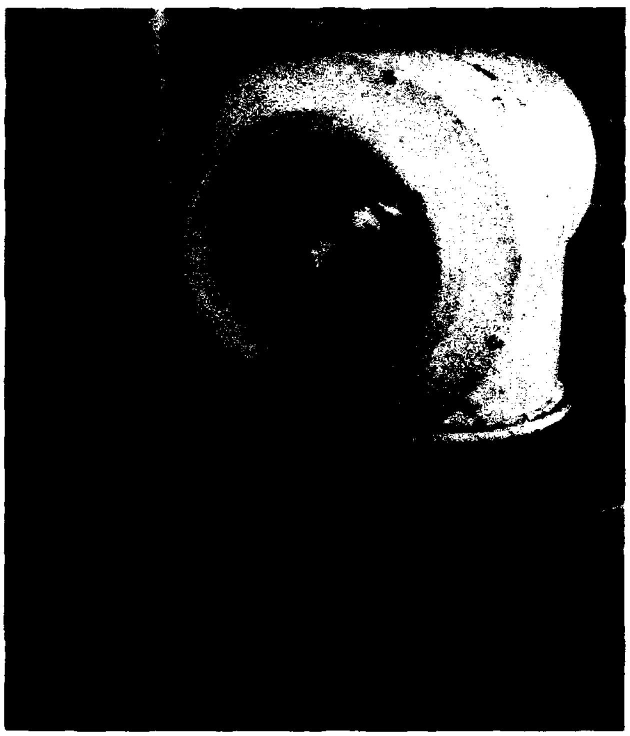
The horizontal separator is intended to intercept spray that would normally strike a vertical surface, such as a bulkhead, downwind of the SIU (Fig. 4). It operates on the principals of momentum and coalescence rather than relying on gravity for water collection. Previous experience with a prototype horizontal collector showed that if water was entrained in an air stream of significant enough velocity to cause an air plug at the inlet of a dead-ended or constricted separator, collection efficiencies would approach zero. To alleviate the problems encountered with the prototype unit, a flow-through horizontal separator was designed and tested. The spray-laden air stream enters the separator through the inlet, where it then is diverted around the convex baffle. Large water droplets, because of their momentum, collide with the baffle and are separated from the air stream. This separated water then runs along the baffle surface and collects on the rim, falling to the bottom for collection in the tank. After passing the baffle, the air stream enters a chamber that is approximately twice the area of the inlet and the annulus around the baffle. This causes a proportional decrease in air stream velocity. The smaller droplets that were not separated from the air stream at the baffle now encounter a mesh screen. These slower moving droplets coalesce on the screen and, when sufficiently large, run down the vertical screen wires to be collected in the tank.

The accumulating water in the tank is measured with a capacitance-based device mounted inside the tank. The water level is sensed by a capacitance change detector circuit. The circuit consists of five sections (Fig. 5):

1. A free running 555 timer (U1a astable mode), whose output is a square wave.



a. Cutaway view.



b. Mounted on SIU.

Figure 4. Horizontal spray separator.

2. A controlled 555 timer (U1b monostable mode), whose output is a pulse (width proportional to capacitance of the sensor.)

3. A water level sensing capacitor, which is a single 24-gauge, Teflon-insulated wire laced around the inside of the collection tank (C6). The center conductor of the wire is one plate of the capacitor. The other plate is the water in the tank, which is the grounded side of the circuit. The wire is wound in a W pattern inside the tank (Fig. 6). This configuration is self-compensating for varying tank attitudes. Increased water depth causes increased capacitance, which in turn causes a longer output pulse from U1b.

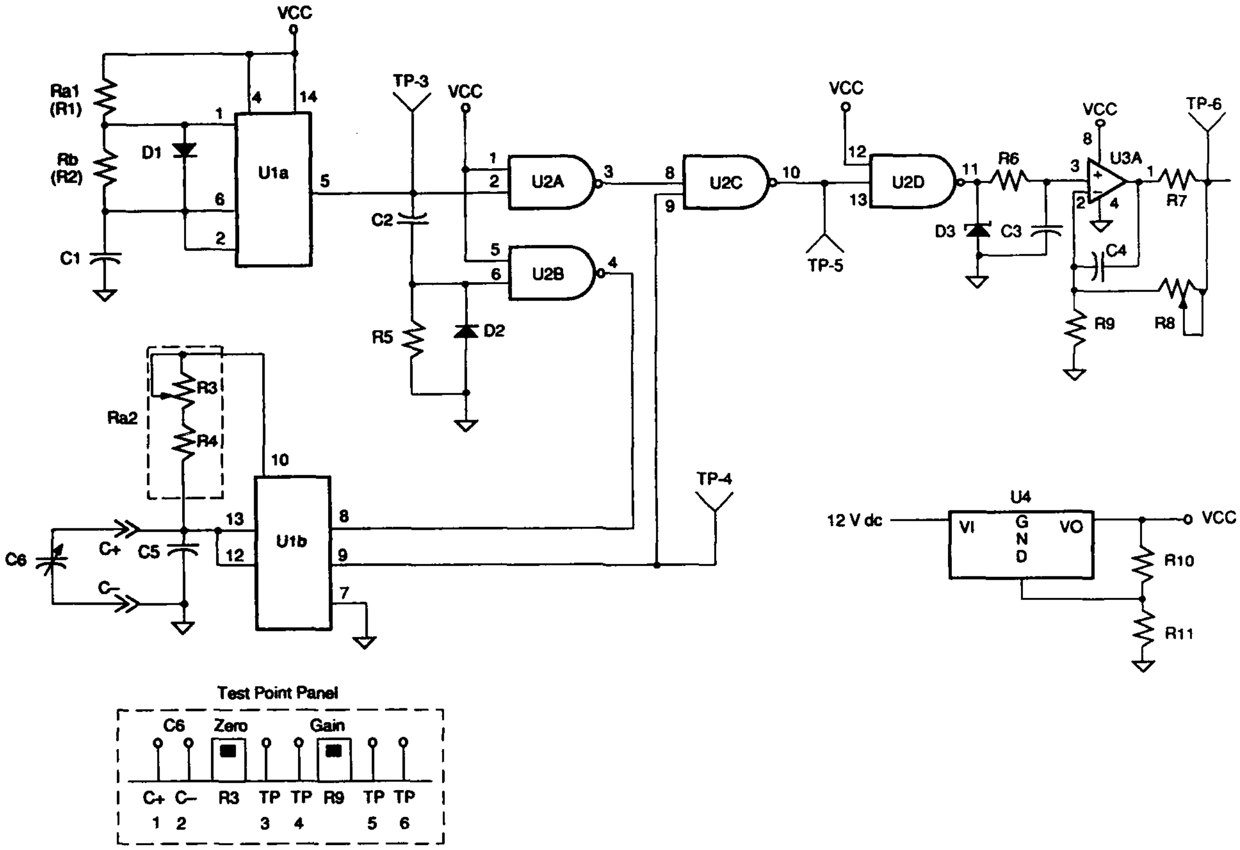


Figure 5. Water level measuring circuit diagram.

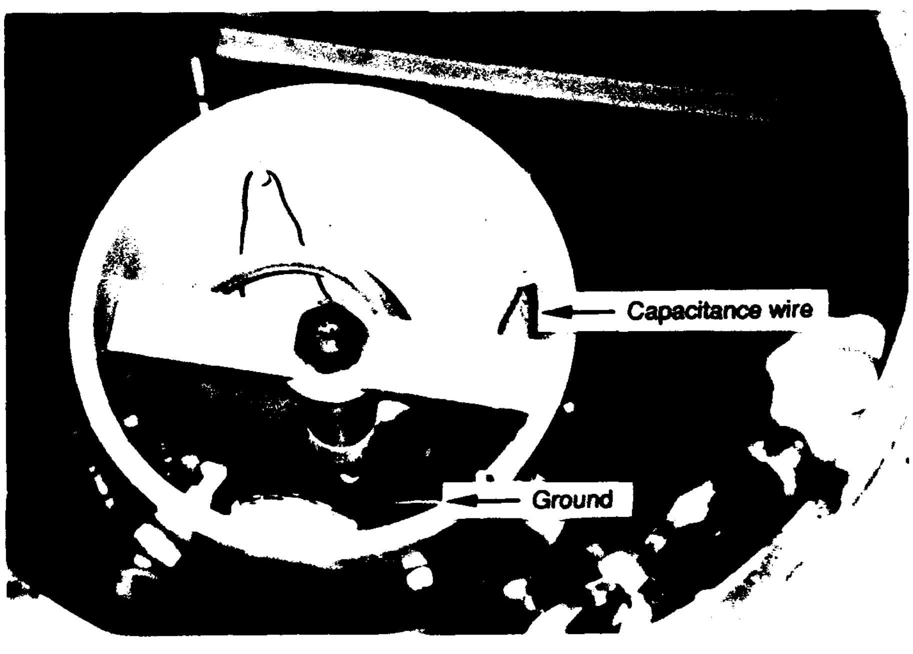
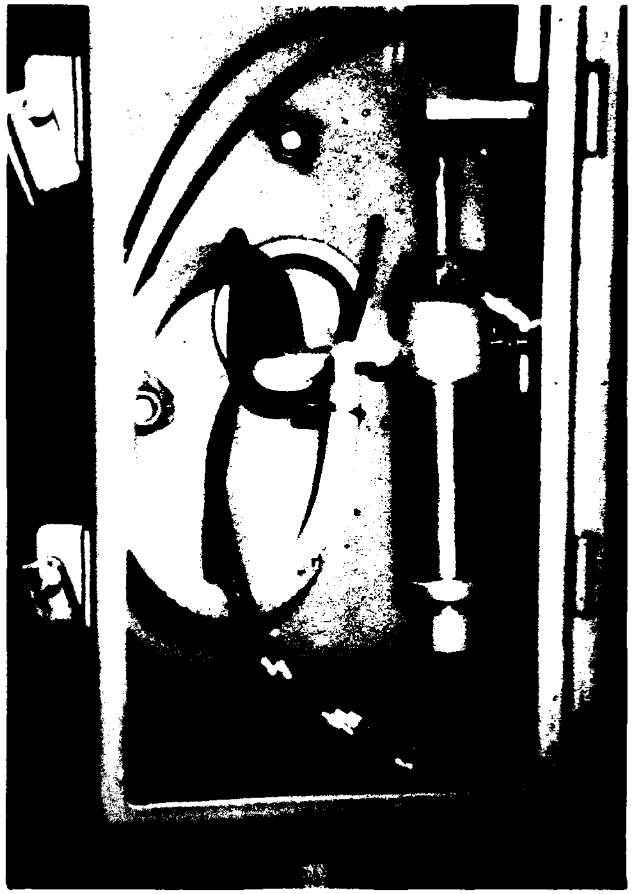


Figure 6. Top view of capacitance wiring in collector tank.

a. As mounted on SIU.



b. Interior of transducer box.

Figure 7. Icing detector.

4. A logic section (U2), whose output is the difference in pulse width between the astable and the monostable timers.

5. An integrating amplifier (U3), whose output is a dc voltage proportional to depth of water in the tank.

The dc voltage output feeds into the data logger, from which it is sent to a storage module. The circuitry is supplied with 12-V dc and internally regulates to 5.3-V dc. A Zener diode (D3) maintains the output pulse level from U2D at 5.1-V dc. (This device is currently operable only with fresh water. Using it in salt water will result in biased depth measurements and faulty readings.)

Ice accretion is measured with an ultrasonic ranging transducer similar to those used in automatic range-finding cameras. The transducers are mounted in an enclosure at the end of the arm projecting from the SIU shown in Figure 7a. The transmitting and receiving transducers can be seen at the top of the opened enclosure in Figure 7b. Note also the thermocouple wire projecting into the box, which is used for sound velocity compensation. A high-frequency acoustic pulse is emitted from the transmitting transducer and the reflected sound is registered by the receiver. The time lapse between the two signals covers twice the distance from the modules to the surface being measured. As the velocity of sound in air at a given temperature is known, multiplying this quantity by one-half the elapsed time will give the distance. As ice accretes on the surface, the elapsed time between sending and receiving the signal decreases, indicating a build-up on the surface.

The range-finding system consists of three basic components: the ultrasonic transducers and driver module (Massa Products Corp. Model E-201A/150), a board to convert the range to a voltage, and the data logger to collect and average the data. The ultrasonic ranging module transmits a 150-kHz

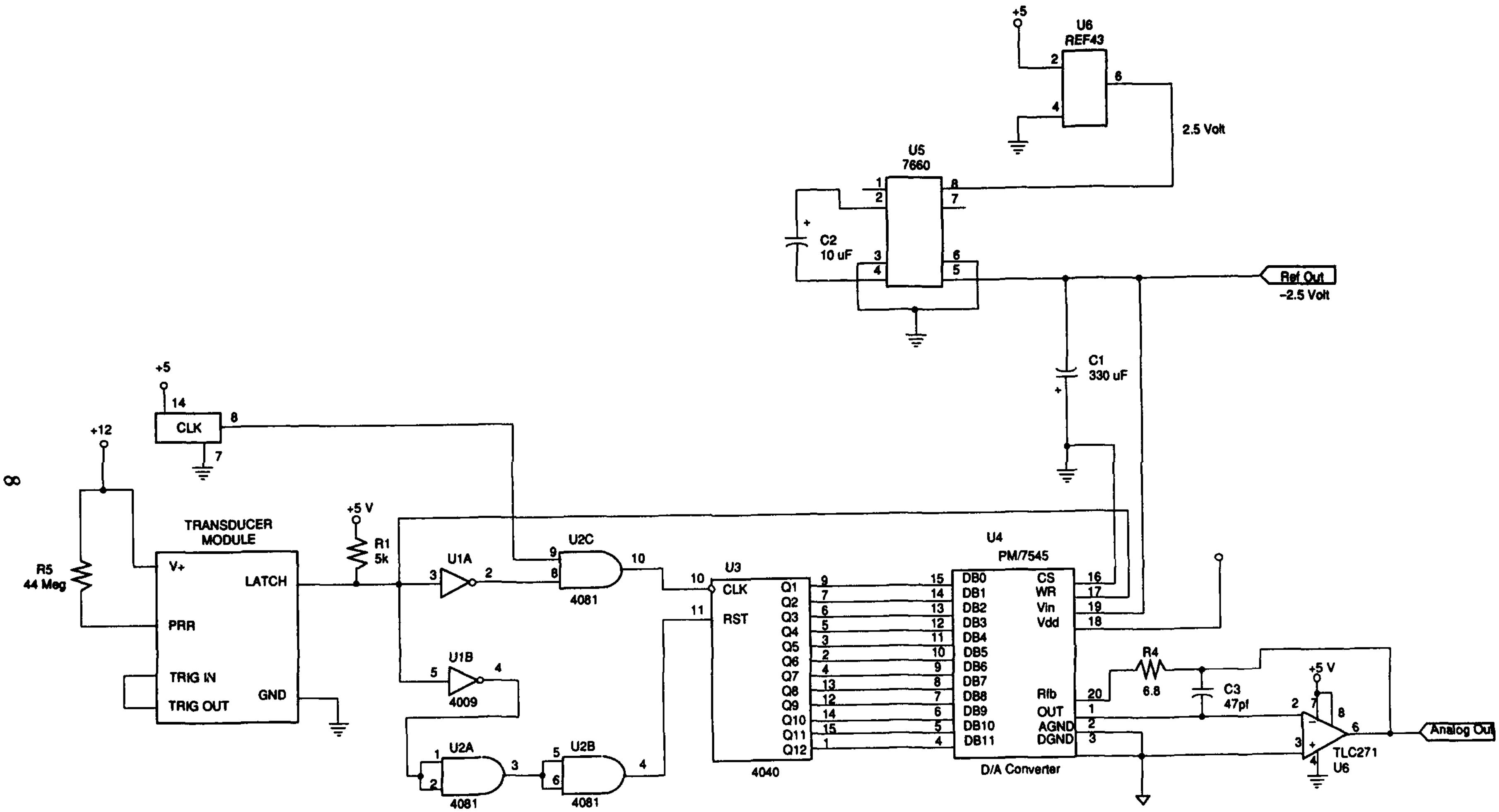


Figure 8. Ultrasonic pulse-width-to-analog-output circuit diagram.

narrow beam (10° cone) acoustic pulse from the transmitting transducer. The receiving transducer detects the reflected pulse when the transducers are adjacent and the module provides a digital latch output pulse.

The latch output pulse width is directly proportional to the distance the sound pulse travels from the transmitting to the receiving transducer. The Inverse Sound Velocity (ISV), in microseconds per millimeters of total sound path, is influenced by the ambient temperature according to the following relationship

$$\begin{aligned} ISV &= 3.937 \times 10^4 / \left[1.3044 \times 10^4 \times \sqrt{1+(T/273)}\right] \\ &= 3.01825 / \left[\sqrt{1+(T/273)}\right] \end{aligned}$$

where the temperature T is in degrees Celsius. The distance from the transducer to an object can then be found from the elapsed time (latched output pulse width) using the following relationship

$$\text{Distance (mm)} = \text{Elapsed time } (\mu s) / (2 \times ISV).$$

As an example, for an elapsed time of 5826.8 µs at 20°C, the inverse velocity would be 2.9134 µs/mm and the range 1000 mm (1 m).

Because time measurement resolution of the data logger is insufficient for this application, a circuit was designed to convert the pulse width output to an analog voltage (Fig. 8). Since the counter and the Analog-to-Digital Converter (ADC) of the ultrasonic ranging circuitry are 12 bits (4096 counts), a method was designed to maximize the resolution. With an average range of 1.22 m, the time for sound to echo off a target is approximately 7100 µs at 20°C. To have the entire range fit into the counter, the clock frequency would have to be 500 kHz. This results in a maximum resolution of about 0.76 mm. With a clock speed of 2 MHz and a 7100-µs travel time, the number of counts generated is 14,200, which would fill the counter three times with a residual of 1920 counts. This increases the resolution to 0.17 mm, while decreasing the maximum measurable range to a span of 0.35 m. The result is that the measurement obtained is of relative ice thickness, rather than distance from the transducer to the ice surface. As high-resolution ice thickness is the desired measurement, this technique works out nicely.

The circuit gates the output pulse with the 2-MHz clock and feeds this to a 12-bit Digital-to-Analog Converter (DAC) with a 2.5-V full-scale output, which in turn goes to the data logger. In the example cited, this would be 11,653 clock pulses, which would fill the counter twice and leave a residual of 3461 counts, resulting in a 2.11-V output from the DAC. This system measures absolute range changes and relative ranges, since the full-scale output is 702.82 mm total path or 351.41 mm reflected path length. The least bit measurement is therefore 0.08 mm reflected for output from the DAC, but the data logger is bipolar and thus has half the resolution (0.17 mm). The transducer range is between 0.13 and 1.52 m, with an optimum range of 1 to 1.5 m.

PERFORMANCE SPECIFICATIONS

Performance specifications for the instrumentation have been developed from laboratory testing and field experience. The original specifications were a consensus among the Principal Investigator, DTRC, the CRREL instrumentation people and the analytical modelers. Design parameters for the equipment have also evolved, with the knowledge gained from the first sea trial (aboard the USS *Yorktown*) incorporated into the design of the current models. Familiarity with the design parameters will assist field personnel in installing the equipment, while knowledge of the performance specifications will aid them in evaluating the operation of the various equipment during periods of data acquisition.

The primary design requirement for the SIUs was that they be stand-alone units, containing their own power supplies. Implied was that data acquisition and storage were to be self-contained. A second critical requirement was robustness. The units on the main deck must be able to withstand the impact forces of green water, estimated at 28.7 kPa (4.2 lb/in^2). For this reason, the units were designed so that a reinforced edge would face in the direction of ship's travel. The units needed to be reusable. Unobtrusive sacrificial mounting pads or chairs were designed for installing all deck-mounted equipment (Fig. 9). This was especially applicable to the lower decks, in particular the main deck. For this reason, deck mounting needed to be strong enough to avoid wire rope braces, which would be a tripping hazard. Equipment installations could not alter the ship's structure, although welding to the decks was permissible where approved. External instrumentation and power cabling, where necessary, had to be minimal and unobtrusive.

Design parameters for the instrumentation were also established. One important consideration with the SIUs was that the equipment enclosures minimally interfere with the measurements, i.e., the instrumentation should not adversely alter the phenomenon being measured. For this reason, the ultrasonic ranging transducers were mounted at the end of an arm projecting from the rear of the enclosure and the horizontal separators were adjustable to optimize air stream flow. The camera housing units were also adjustable in two axes for aiming. Variability in the inlet openings for both the horizontal and vertical collectors was also necessary owing to the possibility of varying amounts of spray that may be encountered at different deck levels. Inlets for the collectors were to be 1 m above the deck.

Power supplies, both pneumatic and electrical, needed to be accessible for ease of recharging and replacement. For this reason, the power systems were designed modularly. Battery trays can be unplugged and removed or recharged in place, while the air cylinder is also easily removed for recharging. As modular design enables quick repair and changes in design configuration, most major components are interchangeable, i.e., tanks, spray collectors, ultrasonics, etc., although recalibration of some instrumentation may be necessary.

Instrumentation performance specifications were also refined after the *Yorktown* cruise. The current specifications for the spray measurement instrumentation are a sampling frequency of 1 second, with a measurement error of ±10% full scale, measurements being an average of 12 samples to reduce noise; the drain valve being able to withstand three cycles of solid freeze–thaw; and the tank capacity being 11.4 L of water, the water volume being measurable to 2-cm^3 or less resolution, with the tank draining automatically when full. The ultrasonic ice thickness measurement transducers are to have a range of between 0.13 and 1.52 m, with a resolution of at least 0.22 cm. The frequency of ice thickness measurement during icing events will be 30 minutes, with three samples taken per measurement. Temperature and battery voltages are to be monitored and recorded every 4 hours.

The video cameras are to be capable of recording spray events. A wash–wipe apparatus will be installed to keep the camera enclosure window clear while using minimal washer fluid. All instrumentation will be capable of withstanding sustained shock loads of twice the force of gravity (2 g's). Designs are to minimize radio frequency emissions and susceptibility. Deck-mounted equipment will operate in a temperature range of –10 to 30°C. The SIUs will operate unattended for up to 24 days on internal power.

INSTRUMENTATION INSTALLATION

The SIUs and CUs are installed on the ship's decking, while the CEU is installed inside the ship as close to the CU as feasible. Lifting eyes are provided on top of each SIU to assist in moving and placing the units. Special care must be exercised when moving the units by crane to avoid overhead wires and masts. Deck-mounted equipment must be cleared with the ship's engineer to avoid on-deck equipment arcs, blast zones, underway replenishment stations and other hazardous areas. The deck-mounted units, as described earlier, are bolted to sacrificial chairs welded to the decking. It is important to know where the equipment is to be located, as deck materials differ and the members that are to be welded to the deck must be of the same material as the decking. If the mounting material or configuration is not certain, extra mounting members must be supplied to cover all contingencies. The ship's engineer should be contacted whenever any welding or other alteration is to be done to the ship. Special welding procedures and

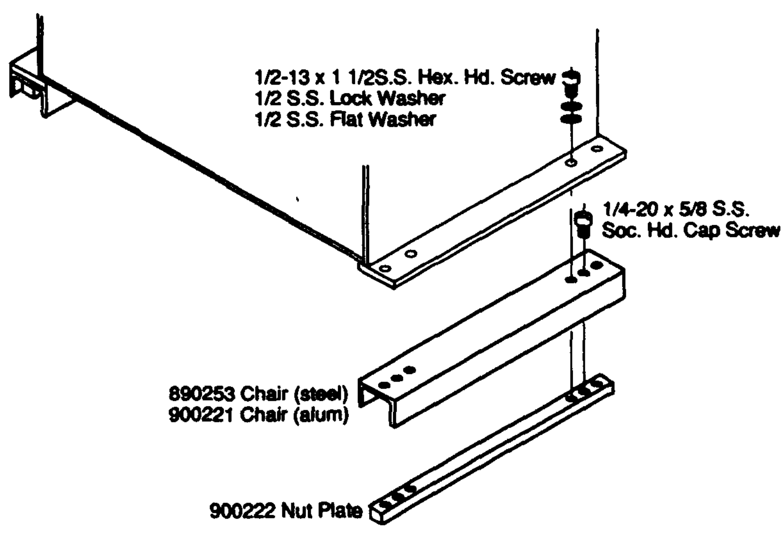


Figure 9. Mounting of SIU to deck (1 in. = 2.54 cm).

surface preparations may be required, depending on the location on the ship and the materials involved. Ship-specific procedures such as "hot work permits" should be followed. A fire watch is required for all welding work. Extra caution must be exercised around sensitive areas, such as ammunition magazines, for obvious reasons.

As mentioned before, the SIUs are mounted to the ship's deck via sacrificial chairs (Fig. 9). These chairs have nut plates bolted to them to allow easy mounting and dismounting of the SIU. This also reduces the amount of sacrificial hardware. To locate the chairs, attach them to the SIU and position the unit where desired. Rough alignment of the rangefinder transducer box should be done at this time as final adjustment of the arm will be limited. The use of an alignment jig (Fig. 10) will

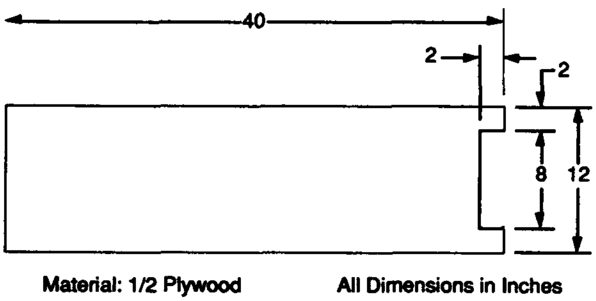


Figure 10. Alignment jig for ranging transducers (1 in. = 2.54 cm).

greatly expedite this procedure. Tack weld the chairs to the deck and remove the SIU. Complete the weld around the chairs. Since decking is generally not flat, it may be necessary to attach scabbing plates or angles to the chair to ensure that the SIU will attach properly. If the deck is only slightly uneven, building up a weld bead may be sufficient. The minimum weld bead should be 6.4 mm (1/4 in.) for steel and 9.5 mm (3/8 in.) for aluminum. A heavier weld bead is recommended in locations, such as the main deck, that may experience green water. Clean and paint the chairs and repaint any affected deck areas at this time to reduce corrosion. Remount the SIU to the chair, making sure the bolts are well torqued (about 113 N m or 83 lbf ft) to the nut plates. Open the door to the enclosure to verify the presence of a drain hole at the lowest corner of the SIU. If one is not present, a 12-mm (1/2-in.) hole should be drilled there to ensure proper drainage. Touch up any dings or scratches with deck paint.

With the SIU mounted to the deck, the unit is now ready for configuring. If the unit is to act as a vertical collection instrument, remove the protective cover, exposing the funnel and debris screen (Fig. 3b and 12a). In areas where large volumes of water are predicted, such as on the main deck or forward locations, one of the various-sized orifice plates (101.6, 146.0 or 249.2 mm ϕ) may be required. This is bolted to the top of the funnel (Fig. 11). These orifices will decrease the tank intake area by 69.2,

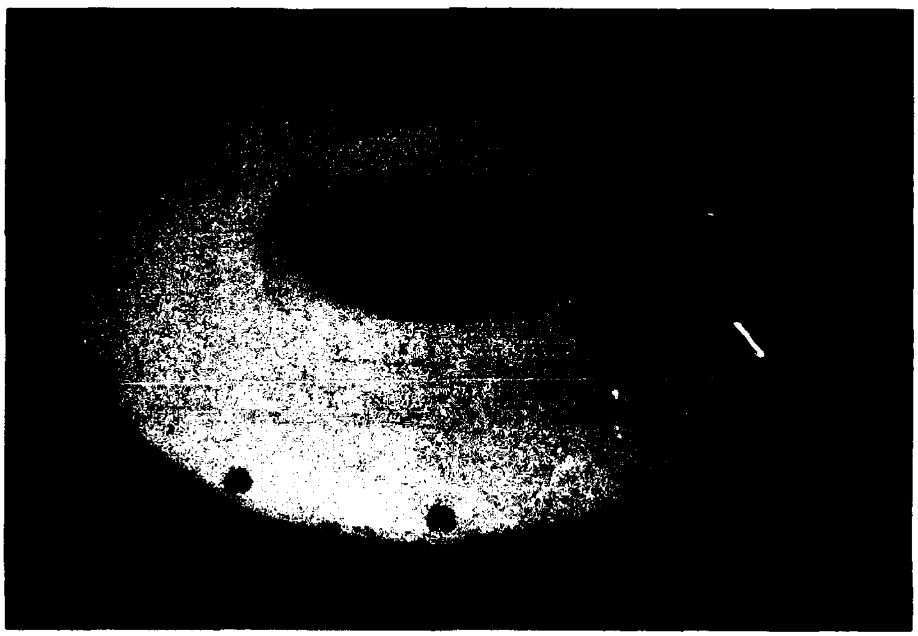
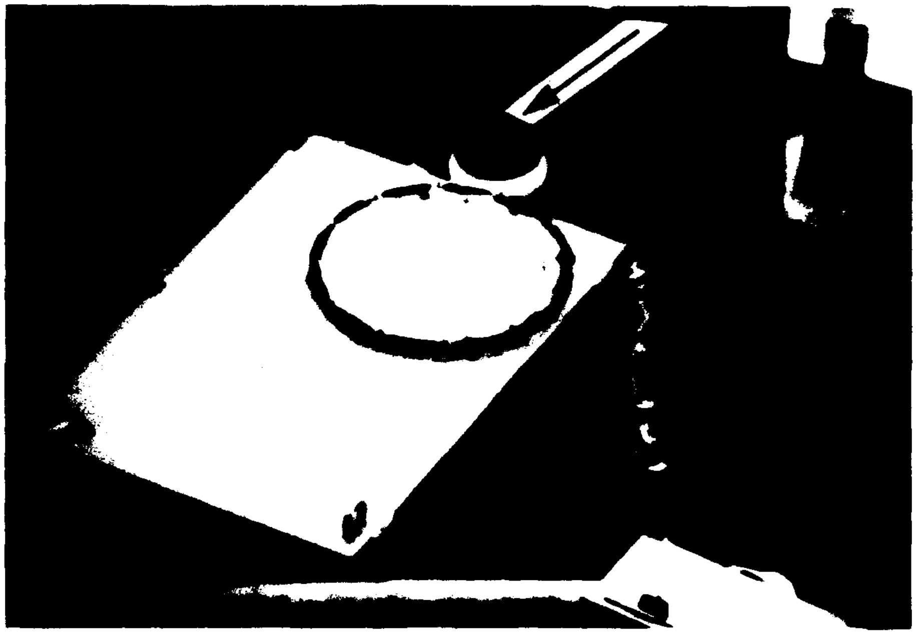
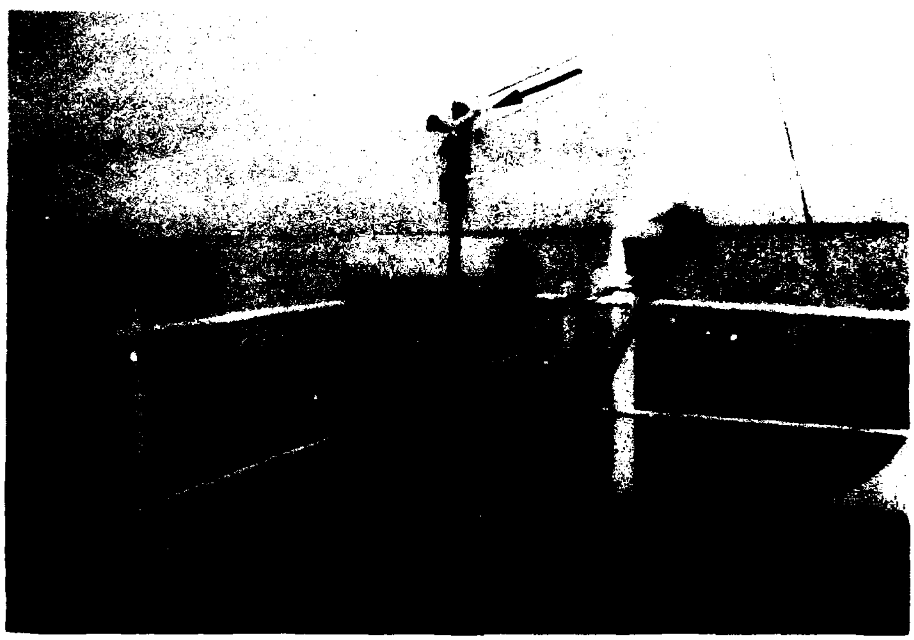


Figure 11. Restricting orifice mounted to vertical spray collector.



a. Commercial vertical collector.



b. Commercial anemometer.

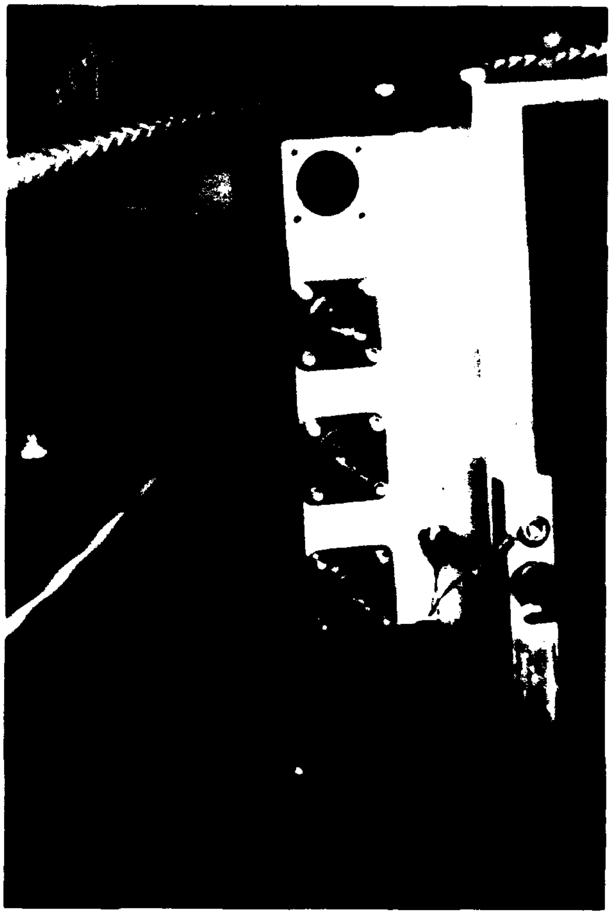
Figure 12. Externally mounted SIU instrumentation options.

55.8 and 24.6% respectively. Experience and ship dynamics will dictate when the use of an orifice is necessary. During the Aleutian cruise, when 8-m seas were experienced aboard the *Midgett*, no orifice plates were used. To obtain the best measurement resolution, it is recommended that these orifices not be used unless heavy seas are predicted and the SIUs are located near the bow. In addition to the SIUs mounted on the lower decks to gather spray flux data, mounting a vertical SIU on the flying bridge is recommended to collect baseline data on other moisture fluxes, such as rain.

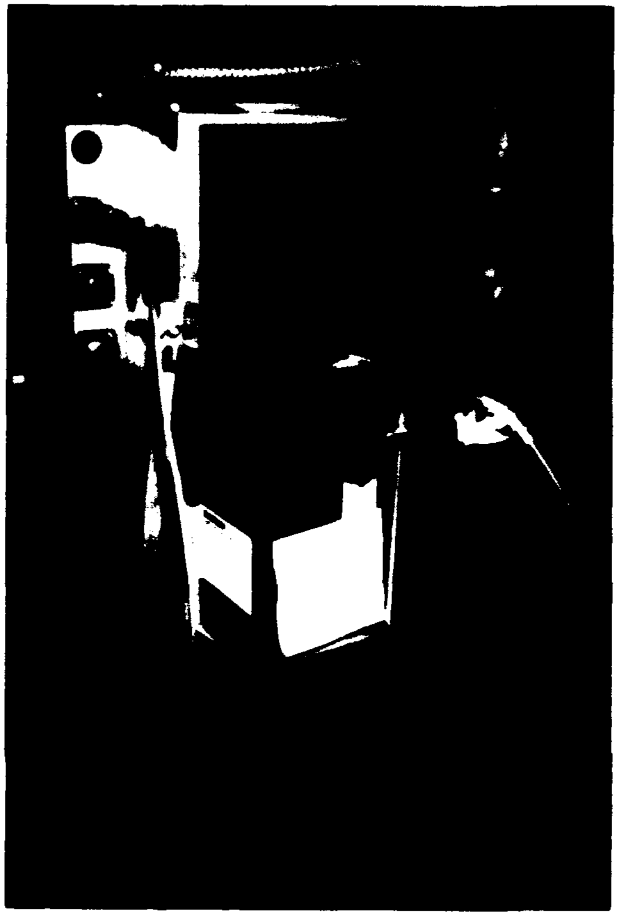
If the unit is to be configured as a horizontal spray collector, it is necessary to mount a horizontal separator to the top of the unit (see Fig. 4a). With the protective cover removed from the funnel, align the 343-mm ϕ aluminum screen assembly above the screw holes on the funnel rim. Carefully place the separator with its baffled end pointing upwind on top of the screen. Bolt the separator to the SIU through the screen. The assembled unit will look as shown in Figure 4b. As with the vertical collector, orifices can be used to reduce the flow of moisture into the separator. These would mount to the front of the separator on the face of the intake collar. Again, these should only be used on lower decks and if heavy seas are predicted. No horizontal separator orifices were used in either the *Yorktown* or *Midgett* cruise.

Auxiliary instrumentation can now be mounted to the unit. During the *Midgett* cruise, two boxes had Young model 50202 rain gauges mounted in the prows to cross check the vertical collectors (Fig. 12a). Also, provisions have been made to mount an anemometer to the door of the SIU (Fig. 12b). While the rain gauge can be a valuable verification tool, the anemometer, which measured both wind speed and direction, proved useless because of turbulence encountered at its location. A fixed anemometer may prove to be more useful in this application. Mounting and interfacing extra instrumentation will not be further discussed.

The next step is to power up the boxes. The 12-V dc electrical power, provided by three trays containing two gel cell batteries each, is supplied via three connectors and plugs (Fig. 13a). Battery trays slide into their slots and are locked into place with keeper bars (Fig. 13b). The most common mode of failure for the batteries is a broken plate, so care must be taken not to strike the batteries or trays against anything when handling them. Over-tightening the retaining bar across the top of the batter-

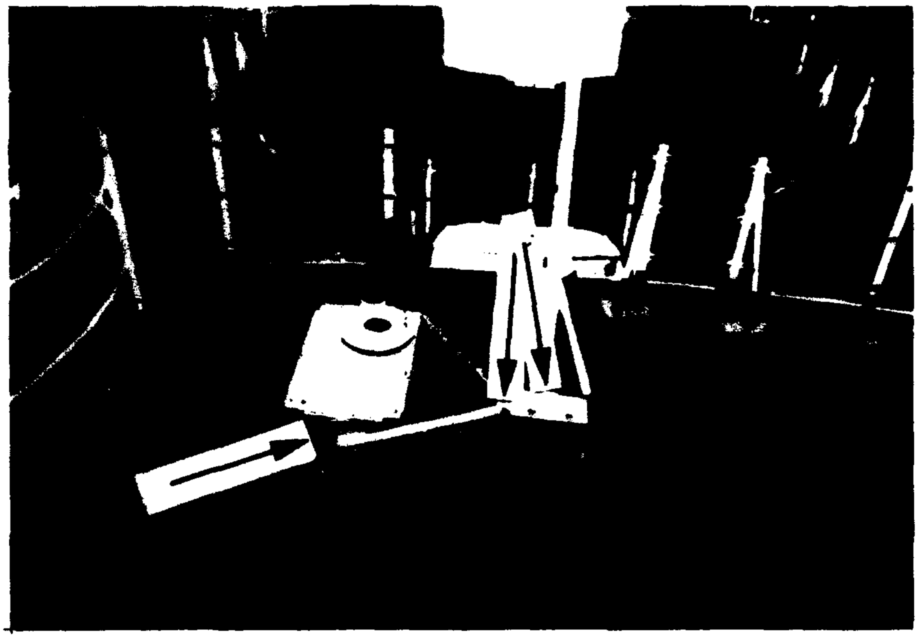


a. Power connections.



b. Installing batteries.

Figure 13. Battery installation.



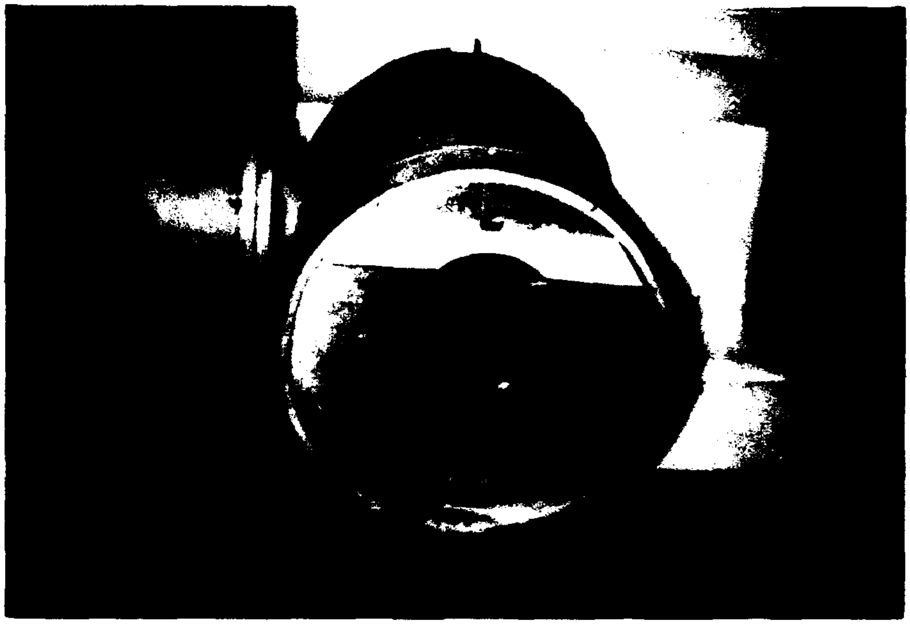
a. At deck (note articulation joints).

b. At curved bulkhead.

Figure 14. Aiming ultrasonic range transducer.

ies may also crack the cases or damage the plates, so care must also be exercised when servicing individual batteries on a tray. The *Instrumentation Operation* section and Appendix A contain more complete startup instructions.

With power to the boxes, the aim of the ultrasonic range transducers can now be fine-tuned. These devices work best when aimed at a smooth, flat surface. If the transducer is to be aimed at a rough, grainy surface, such as the non-skid surface found on decking (Fig. 14a), the area must either be smoothed off or a target must be attached to the decks. Care must be exercised when mounting a target as it may alter the icing environment, thus resulting in erroneous data. For this reason, it is recommended that surface preparation be the option first considered. Another factor that will improve the signal-to-noise ratio is transducer alignment with the target. The more perpendicular the alignment, the higher the quality of the signal returned. Spray flux and ice accretion measurement directions should be the same for each individual unit. Units that will measure vertical spray fluxes should have the transducers aimed at the deck, while those measuring horizontal fluxes should be aimed at the adjacent bulkhead. The transducers should be 100 to 150 cm from the surface to be measured for best results. Curved target surfaces should be avoided, although they are acceptable when properly aligned (Fig 14b).



a. Front view.

b. On ship.

Figure 15. Camera Unit (CU).

Installing the camera equipment, with the exception of routing the cabling, is not as complicated as installing the SIUs. After a suitable location is found, preferably with an unobstructed view of the bow area and some of the SIUs, the mounting plate and CU are aligned. The camera angle is adjusted through two articulation joints (Fig. 15). It may be helpful to bring the CEU on deck to assist in rough and finish alignment. Mark the location and orientation of the mounting plate and remove the CU from the plate. The plate is then welded to the deck. Clean and paint the deck and plate area to prevent corrosion. Bolt the CU to the sacrificial plate and fine tune the aim. With the camera aligned, run a

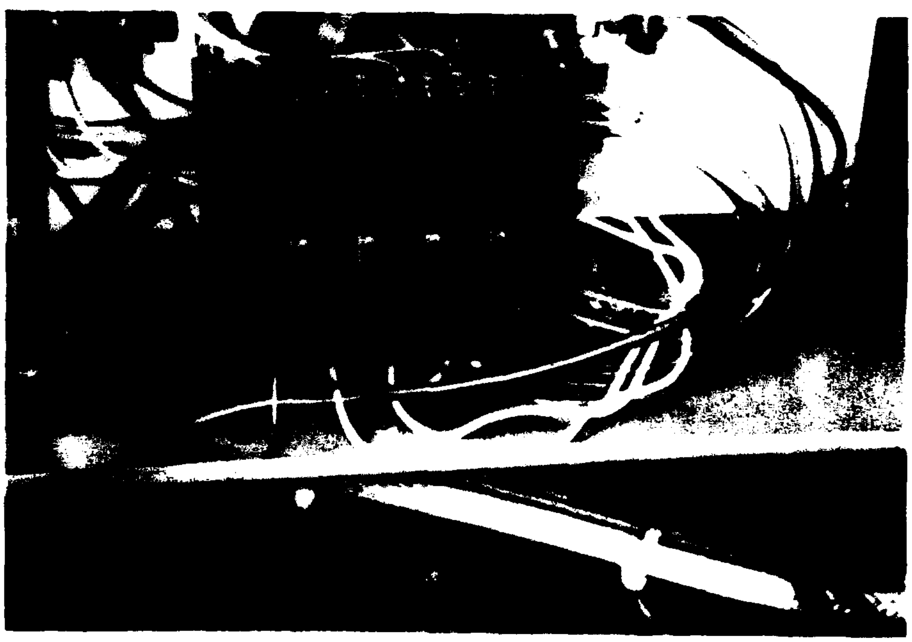
cable from the camera electronics unit to the camera unit. Wire wraps with screw tabs are especially helpful when running the cable. They can be used to tie the cable to ship rails or other components and attach it to the overhead supports inside the ship. Coordinate the cable placement with the ship's engineer. The electronics unit should be secured in an inner room. Care should be taken to isolate the CEU from ship vibration and shock loading. After all the connections are made, the outside connections waterproofed and the cable secured, power up the system and do the final checkout. This is also a good time to check out the other functions of the video system, such as the wash-wipe cycling. Make sure the washer reservoir is full and ample supplies of videotapes and washer fluid are on hand for the cruise. Quantities will depend on cruise length and severity of weather, but a safe estimate would be 10 videotapes and 1 L (1 quart) of fluid per day of data collection.

INSTRUMENTATION CALIBRATION

One of the most important tasks that must be done for the proper operation of the instruments is calibration. This applies primarily to the collection tanks. The video equipment does not need to be calibrated, although some adjustment to the image, such as white balancing, may be necessary. The ultrasonic range transducers do not need to be calibrated, but their temperature-dependent linearity should be checked and confirmed. The horizontal separators can only be conveniently calibrated off-ship. The vertical collectors do not need to be calibrated, as they are a part of the collection tank system. They can be checked against commercial rain gauges, when available, to verify their accuracy. The instrumentation should be calibrated with all equipment in place and in its final operating configuration whenever possible.

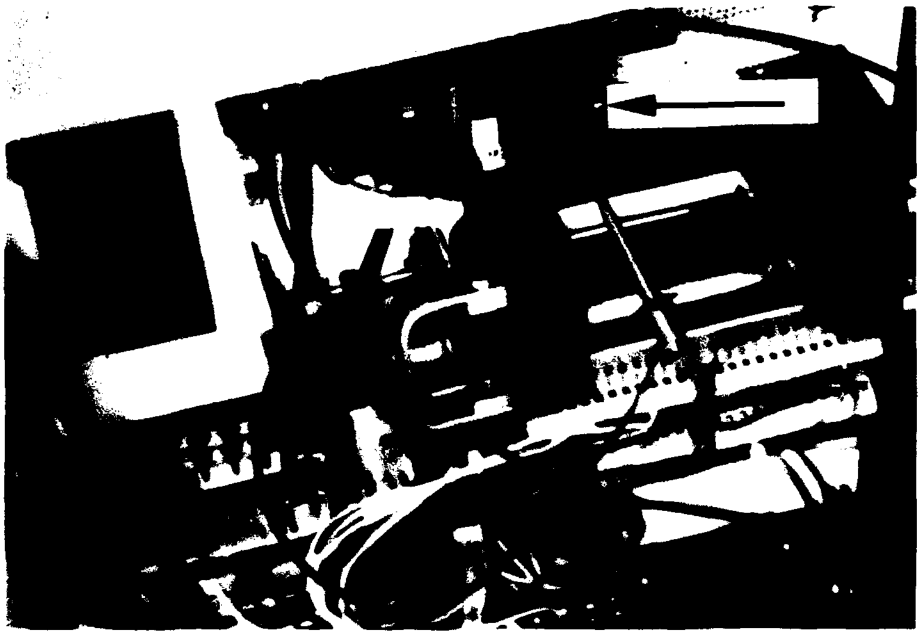
Collection tanks

To calibrate the collection tanks, a set of 1-L graduated flasks, a multimeter or oscilloscope, and some jumper wires are required. Before calibration, the tank must be filled and drained once so that adjustments are made with the tank empty and wet. The tank is drained as follows. Open the electronics enclosure and locate the solid state relay board (see Fig. 16a). The relay board is near the bottom of the enclosure and has four red modules on it. There are also two terminal strips on the relay board. Use the upper terminal strip. To drain the tank, the third and fifth terminals, counting from the right side of the board, must be connected to ground (battery minus). This will open two solenoid valves (there will be a click), and water will



a. Solid-state relay board.

Figure 16. Test point locations for tank calibration.



b. Capacitance sensor board.

Figure 16 (cont'd).

run out the drain pipe. The connection to ground need be only momentary. The drain valve will remain open until the third terminal from the right is grounded again. There will be a click and escaping air as the drain valve closes. Now the tank is ready for zero adjustment.

There are two methods for zero adjustment. The first method requires a two-channel oscilloscope. The second method requires a digital voltmeter.

Method 1

Connect the vertical channels of the oscilloscope to monitor Test Points (TP) TP3 and TP4 (see schematic, Fig. 5, and Fig. 16b). TP3 is the circuit free-running frequency (wave form 1 on Fig. 17). TP4 is the output pulse proportional to the capacitance of the sensor in the water tank (wave form 4 on Fig. 17). Voltages are measured between the test points and ground. Adjust zero pot R3 on the left side of the test point board (see Fig. 5) until the wave forms are identical. Verify by moving the scope lead from TP4 to TP5. Rotate R3 clockwise until a very narrow negative pulse is observed, then rotate R3 counterclockwise until the pulse just disappears. The circuit is now zeroed. The output voltage at TP6 should now be less than 20 mV.

Method 2

Connect a digital voltmeter to TP6 and adjust R3 until the output voltage just reaches a minimum.

The tank is adjusted at full scale by filling it until water runs out the overflow pipe (11.4 L). At this point, adjust R8 (right hand side of test point board) until output voltage reaches 2.500-V dc. Calibration of the collection tank is now complete.

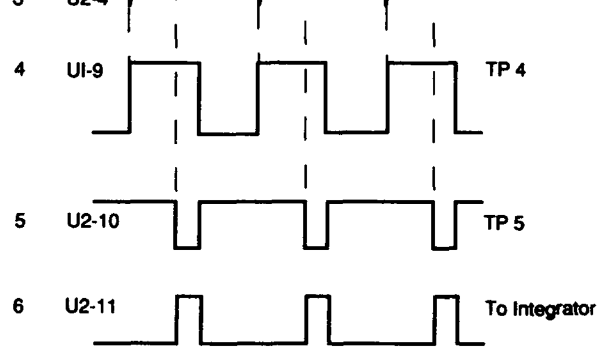


Figure 17. Wave forms for collection tank test points.

Figure 18. Checking linearity of collector tank capacitance system.

Although the collection tank system is inherently linear with fresh water, linearity should be checked at least once to ensure proper wiring of the capacitance gauge. The most convenient way to do this is similar to *Method* 2 described above. In this case, however, water is added, 1000 mL at a time, and the output voltage read off the multimeter (Fig. 18) and recorded for later analysis. There is no method to adjust for nonlinearity in this design.

Ultrasonic rangefinders

As mentioned above, the ultrasonic rangefinders do not have an adjustable calibration, but their temperature-dependent linearity should be confirmed before deployment. To do this, place the SIUs in a coldroom with the sensors facing one wall. Cycle the temperature (1-hour cycles) between –9.4 and 4.4°C and back over an 8-hour period. Collect data every 10 minutes and at the end of the test, analyze for linearity and accuracy. Caution must be exercised when running coldroom tests as the transducer modules can burn out when powered up at low temperatures after being cold soaked. The module should be powered up and operating at room temperature before the low-temperature tests are started.

Horizontal separators

The horizontal separator calibration consists of deriving the efficiency curve over a given wind speed range. The current separator design was calibrated over an inlet air speed range of 16 to 71 km/hr. The design does not allow "tweaking" to improve efficiency, so the calibration factor (efficiency) is fixed. Although it is not necessary to recheck the calibration curve for the separators, instructions follow in case verification of the curve or a new design is proposed. A flat, shallow negative slope is the desired result, as a linear function is more easily compensated for when analyzing data. As with the vertical collectors, the use of an inlet orifice will require compensation during spray flux analysis. It may also require recalibration.

Calibration of the horizontal separators requires a garden sprayer (2- to 4-L capacity), a 1-L graduated flask, or a pail, a multimeter and a set of jumper wires, an anemometer and a pickup truck. Obviously, this is a procedure that cannot be done on a ship. Fill the garden sprayer with a known amount of water. With the separator mounted to an SIU, aim the unit so that the axis of the separator lines up with the axis of the truck. With the truck traveling at a fixed speed, check the separator inlet and exit air speeds (exit air speed should be half the inlet speed). Proceed to spray water into the inlet. A finer spray will give a more rigorous measurement, as the droplets are less likely to separate from the air stream. When the sprayer is empty, the water volume in the tank can be measured using either the capacitance system as described in method 2 of the collection tank calibration or by emptying the tank into a bucket and measuring the water

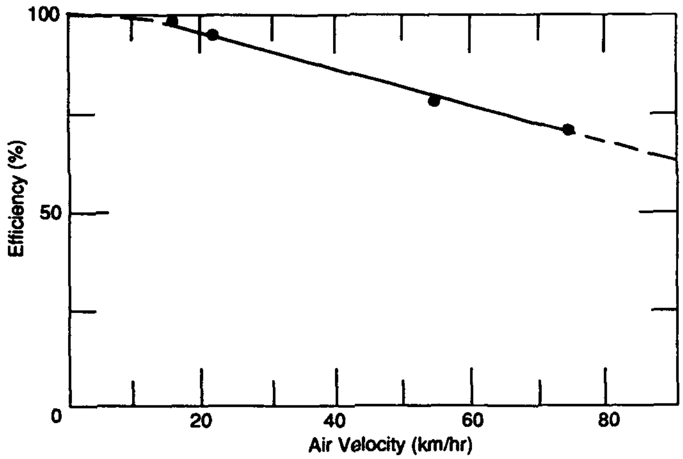


Figure 19. Calibration curve for horizontal separator.

from there. The ratio of water in versus water retained will give the efficiency. Repeating this procedure for several speeds will result in a graph that should be similar to that shown in Figure 19. Always confirm the inlet and outlet wind speeds using the anemometer, as turbulence from the vehicle motion will affect the inlet air speed.

INSTRUMENTATION OPERATION

Operation of the spray–icing units and the videotape equipment is straightforward, as outlined in the two following sections. The block diagrams below outline the general operation of the devices. Some modification of them is possible to tailor their operations to the user's needs. The equipment is generally used only during daylight hours so that video data can be collected at the same time spray and icing data are collected, but this is not always necessary. Night operations may be conducted if conditions dictate.

To initiate operation of the SIU equipment, power must be connected to the electronics. *It is of utmost importance that the temperature of the SIU be at least 15°C to avoid thermal shock failure of the electronic components.* Ideally, the SIU will be installed where the ambient temperature is above 15°C. If this is not the case, then the electronics enclosure must be warmed. This can be done by disconnecting the cables to the various components and warming the enclosure indoors until the SIU is ready to come online. Other methods include warming the enclosure in-situ with a heat lamp or heat gun. Care needs to be exercised to ensure that the components are not heated above 60°C or failure will again be the result. Once power is safely applied to the electronics, they are safe from temperature fluctuations.

The next step is to download the operations program from the memory module to the data logger, which acts as the controller. There are three programs currently available residing on the installed memory module. One is written for use with the SIU in the horizontal configuration, one for the vertical configuration and the last in the vertical configuration with a commercial (Young model 50202) precipitation gauge. To transfer a program from the memory module to the data logger, the memory module and a keypad must be connected to the data logger via a blue wye ribbon cable (supplied). With power to the system, press the following keys:

*D7121 for the horizontal configuration.

*D7122 for the vertical configuration.

*D7123 for the vertical configuration with a precipitation gauge.

This will transfer and initiate the program. To reinitialize a resident program, enter *0. The memory modules have an internal battery that will maintain memory, and thus the programs, for about 24 months after the date of manufacture. This date is printed on the component's label. It is suggested that the programs not be transferred until at sea to conserve power and thus main battery life. See the Campbell manual (Campbell Scientific 1991) and Appendix A for further details.

The video system requires no special actions to start up. Simply connect all the cabling to the required plugs and start. Turn on both the main power switch and the camera adapter switch. The

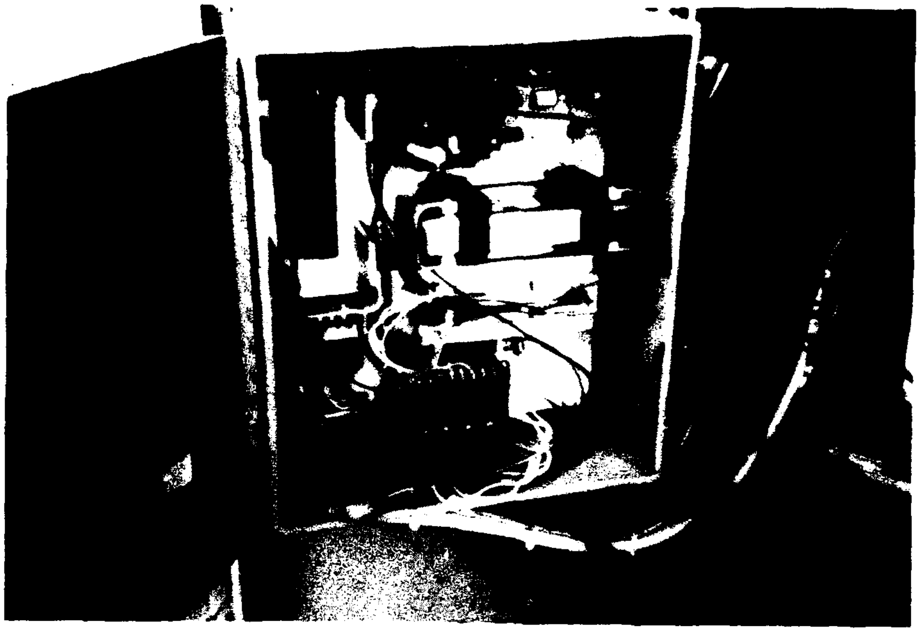


Figure 20. Door-mounted electronics enclosure.

camera should be allowed to warm up about a minute before recording is begun.

Spray–icing units

The spray–icing units are designed to operate unattended on internal power for 24 days. All functions are controlled by a programmable data logger that writes data to between one and three memory modules, depending upon the unit configuration. This hardware, along with the transducer module and the solenoid valves for the ball valve and transducer cylinders, is located in the electronics enclosure mounted to the door of the SIU (Fig. 20). At above-freezing temperatures (0.5°C or higher), the spray collection mode is operational, while below the freezing point (–2.5°C or lower), the ice accretion mode is active (Fig. 21).

During spray collection, liquid water enters the measurement tank as described in the *Theory of Operation* section. As the water accumulates in the tank, 12 readings from the capacitance gauge system are sampled, one every second, by the data logger. These 12 readings are averaged and the average is stored in memory. The data logger then

Table 1. Valve sequencing for spray and icing modes.

Condition	*Valves**	*Action*	*Function*
Icing			
	PV1 & PV2	Energize	Opens ball valve (cylinder C1) to drain tank.
	PV1 & PV2	De-energize	Dead-ends air; holds valve open to drain.
	PV3	Energize	Opens rangefinder transducer window (cylinder C2).
		Wait	(Takes range readings.)
	PV3	De-energize	Closes rangefinder window (cylinder C2).
		Wait	(Repeats PV3 sequence at appropriate time.)
Spray			
	PV1 & PV2	Energize	Opens ball valve to drain tank (cylinder C1).
	PV1 & PV2	De-energize	Dead-ends air; holds valve open to drain.
	PV2	Energize	Exhausts trapped air; closes ball valve (cylinder C1).
	PV2	De-energize	Saves power.
		Wait	(Takes depth readings until overflow—repeat sequence.)

*See Figure B7 for pneumatics diagram.

resumes sampling. When the measurement system determines that the tank is full, the data logger triggers the solenoid valves that control the ball valve air cylinder (see Fig. 3a). The cylinder stays active about 10 seconds, long enough for the tank to drain. The control then switches the solenoids to exhaust and the spring return mechanisms on the ball valve and cylinder close the valve. The measurement cycle thus starts anew.

When the temperature drops below the icing mode trip point, the data logger activates the solenoids controlling the ball valve cylinder, opening the ball valve to drain the tank. The controller then deactivates the solenoid valves to stop the flow of air to the ball valve cylinder and ports the pressurized cylinder and supply tank air to dead-ended lines, thus saving power, reducing line losses, maintaining drain cylinder pressure and leaving the tank in drain mode (see Table 1). This is done to keep the tank from freezing up and damaging the capacitance gauge. The data logger then switches the SIU to the ice accretion mode. Figures B1, B2, B4 and B7 are system schematics that contain the valves and cylinders referred to in Table 1.

In the ice accretion mode, the ultrasonic ranging circuitry is activated. Every 15 minutes, the data logger activates the ranging transducer shutter solenoid, thus activating the shutter cylinder (Fig. 7b). With the shutter open, the ultrasonic circuitry is activated and three readings obtained. The data are stored in the memory module and the shutter solenoid deactivated, thus exhausting the pressurized air and causing the shutter to be closed by the spring-return air cylinder. Measurements continue until the temperature climbs to the spray collection mode trip point, whereupon the mode of operation switches back to spray collection and measurement. Ice accretion data are later analyzed for temperature compensation and signal-to-noise ratio.

A hysteresis band of 3°C (–2.5 to 0.5°C) is programmed into the controller to prevent spray-to-icing-mode oscillations near the freezing point of salt water, which is –2.5°C. This band is software adjustable in the data logger (see Walsh et al. 1991 and Campbell Scientific 1991). The current bandwidth was finalized during the *Midgett* cruise in 1990.

Proper operation of the pneumatic solenoid valves requires a minimum electrical output

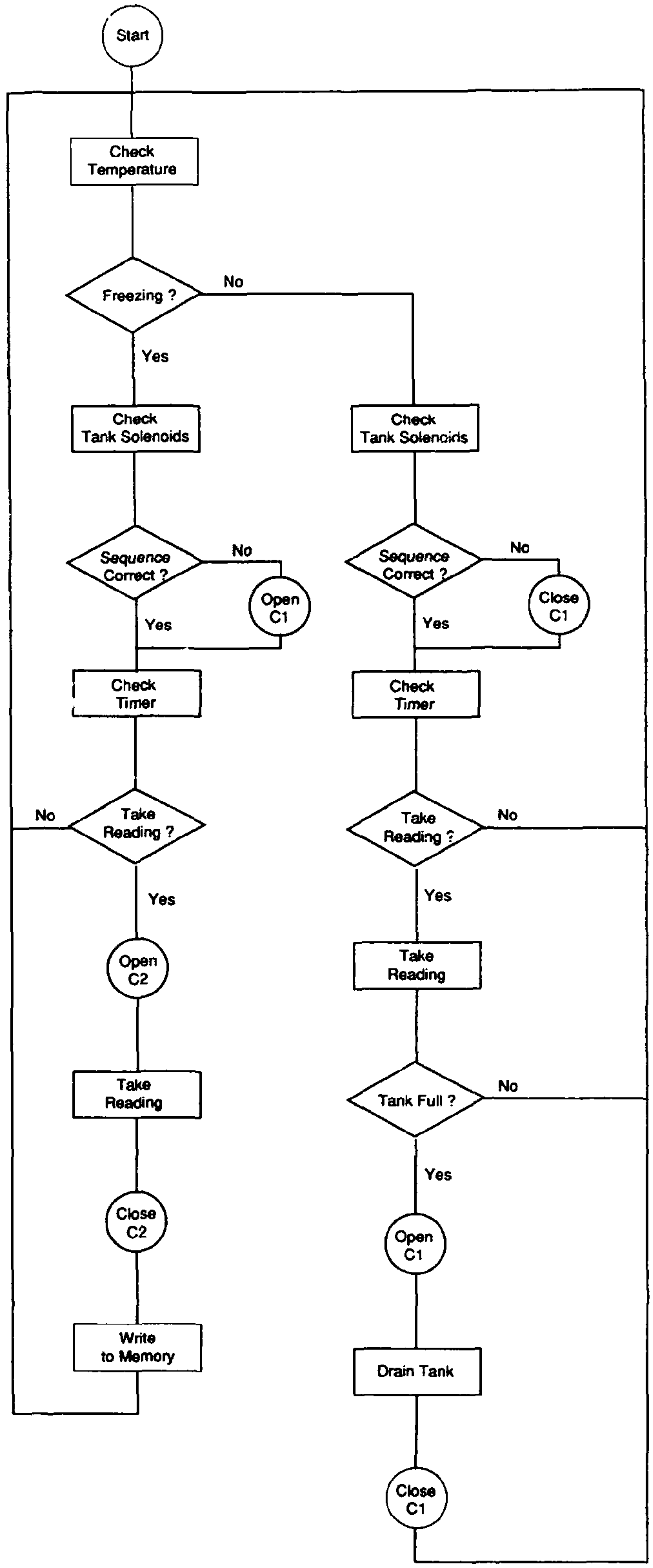


Figure 21. Block diagram for SIU operations.

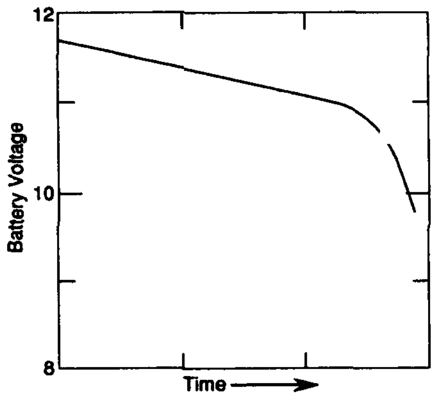


Figure 22. Battery drainage curve.

voltage of 10-V dc. Battery output voltage is monitored by the data logger and the status is indicated by a blinking red light atop the SIU. The battery voltages slowly decrease from their fully charged condition until they approach 10 V, when voltage decreases rapidly (Fig. 22). When voltage drops below the 10-V safe level in a unit, the light stops blinking, indicating the batteries should immediately be replaced or recharged to ensure proper instrumentation operation. The frequency of the blinking light is a 1-second flash per minute.

Current SIUs have no external method for monitoring air pressure. The large capacity of the air tank allows for extended use (21 days), but the tank pressure should be checked whenever possible. Maintenance of both the pneumatic system and the electrical system will be discussed in the *Maintenance* section.

Videotape equipment

Operation of the video equipment is straightforward. All camera and recording functions are controlled from the CEU. These functions include the washer–wiper cycle, tape recording and camera power. The wash–wipe cycles are controlled by means of a three-position toggle and a rotary switch (Fig. 23). The toggle position determines wipe only cycle (up), wash and wipe (down), and wash–wipe off (center). The rotary switch controls the cycle frequency, from one cycle per 7 seconds to one every 12.35 minutes (see Table B2). Each cycle consists of two wipes and, when applicable, a squirt of washer fluid. The washer fluid, contained in a reservoir on the back of the camera unit, is pumped to the glass camera porthole by an automotive washer pump, while the wiper is driven by a self-contained wiper motor–linkage unit at the front of the enclosure (Fig. 24).

The window cleaning system uses very little washer fluid per cycle. However, it is recommended that the fluid be used only when necessary as the wipers do a good job of clearing the window. The less fluid used, the less often the reservoir has to be refilled. Cutting the fluid 50/50 with water will stretch the supply, but is not recommended for

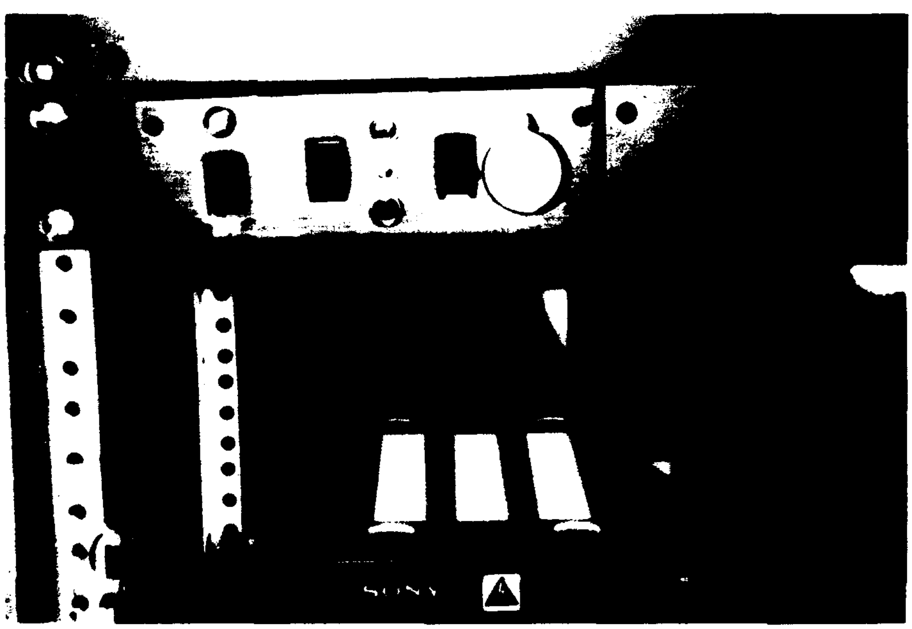


Figure 23. Washer–wiper controls on CEU for CU.

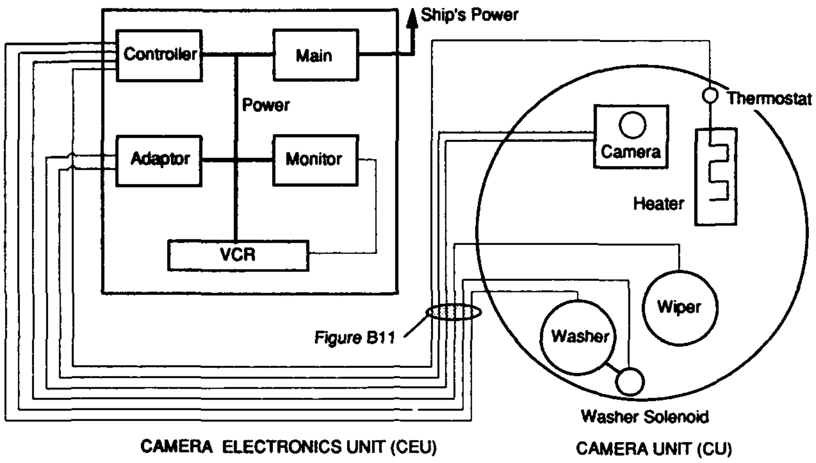


Figure 24. Component layout for video system.

temperatures below freezing. The recommended supply, 1 L per day of data, should be more than adequate. Concentrated fluid is recommended to reduce shipboard storage volume.

The videotape recorder supplied will run from 2 to 120 hours on a standard videotape. During the *Midgett* cruise, the recorder was set for 2 hours as the image resolution is slightly better than at the 6-hour setting. The time interval, however, is up to the discretion of the equipment operator. The quantity of tapes required for the cruise is determined from the tape speed setting and an estimate of the number and length of days during which data are to be gathered.

MAINTENANCE

Although the collectors and camera equipment are capable of operating unattended for extended periods, some maintenance work is necessary to ensure proper and continued operation. Maintenance items for the SIUs include the power supplies and memory modules. For the videotape equipment, the washer fluid and videotape must be monitored. Improper maintenance of the equipment will result in faulty or lost data and may result in equipment damage.

As discussed earlier, maintenance of the SIU power supplies is straightforward. To recharge the batteries in place, simply disconnect the main plug and plug into the recharger (Fig. 25). If this is not convenient, each two-battery tray can be removed and replaced with one containing fresh batteries. It is best to recharge or replace all the batteries in the unit to ensure the maximum run time between maintenance operations. Exercise care in handling the battery trays, as they are heavy and bumping the tray or batteries may cause damage to the battery cell plates.

The air tank is most easily recharged out of the unit. Charging pressure is 15.2 MPa (2200 lb/in.^{2}).

Figure 25. Recharging batteries.

Figure 26. Filler plug location for camera washer reservoir.

Air from the ship's machine room should be of sufficiently high pressure to recharge the tanks. Before sailing, make sure that a means of connecting the tank to an air line is available. It is very likely that an adapter other than that supplied will need to be purchased or built to fit your specific situation. Air cylinders should be oiled with a couple of drops of lubricating oil through the breather hole opposite the piston rod whenever possible. This is especially important for the collection tank cylinder, as it is directly exposed to water. Limited access to this cylinder makes it necessary to lubricate it whenever possible. Check air lines and connections periodically for leaks. A bottle of leak detector sprayed on connections will give a quick indication of a leak. When servicing the air tank, ensure that the regulated output pressure is 207 kPa (30 lb/in.^{2}) after reinstallation.

Memory modules should also be downloaded and the data stored in duplicate whenever possible. For complete instructions on the use of memory modules, see the Campbell operator's manual (Campbell Scientific 1991). To download the memory module, the following are required:

1. An IBM-compatible computer with a serial interface.

2. A 9-pin peripheral to RS232 interface, Campbell P/N SC532 or equivalent.

3. The program SMCOM from the Campbell software package.

The SMCOM program allows data to be downloaded in several formats, including comma delineated ASCII. Programs can be up- or downloaded in a similar manner. The memory modules contain a 3.6-V lithium battery to maintain RAM. The life of these batteries is approximately 2 years from the date of manufacture shown on the cover. Before taking the modules into the field, the battery voltages should be checked with a battery tester. Battery condition is verified using the SMCOM program. A "1" indicates a good battery, while a "0" indicates low battery voltage. If the voltage is low on a module battery, it should be replaced or closely monitored during the cruise. Changing the battery in a memory module is not a simple task, involving soldering of battery leads, so it is recommended that any weak batteries be replaced before field use. It is highly recommended that each day's data be reviewed whenever possible. Failure to review the data may result in the collection of bad data throughout the cruise if problems are not addressed. Unaddressed problems, such as those encountered during the *Midgett* cruise, will jeopardize large segments of collected data.

Maintenance of the video equipment is also essential to proper collection of data. Frequency of tape changes is obvious, depending on tape length and use of the VCR. Store all media in a dry area that is not subjected to strong magnetic fields. At periodic intervals, depending on the wash fre-

quency, the washer fluid reservoir should be checked and filled through the filling plug located on the top of the reservoir (Fig. 26). The capacity of the reservoir is 9.5 L (2.5 gal.). If extended periods of warmer weather are anticipated, dilute the washer fluid 50/50 with water. Otherwise, use it straight. The rating of the fluid should be at least -20°C. If the camera, washer mechanism or wiper mechanism need to be serviced, access is via the flange at the reservoir. Remove the screws and pull the reservoir off the main body of the camera enclosure. The fluid supply tube is connected to the pump via a hose that can be separated at the quick disconnect fitting. This fitting has internal check valves to allow disconnection with the tubes filled. When reassembling the unit, care should be taken to ensure that the supply tube will not kink. The interior of the CU housing must be dry to prevent fogging of the window. A packet of chloride is provided for this reason. The packet may need to be dried periodically in an oven to ensure effectiveness.

TROUBLESHOOTING AND REPAIR

Despite one's best efforts, the instrumentation may be damaged or malfunction. The conditions under which the equipment must operate are among the harshest in the world. Care in installation and maintenance will eliminate most problems, but it has been rumored that Murphy was a sailor, and problems must be anticipated. Although the equipment has been designed for rough conditions, the very nature of the instrumentation and past experience during the two cruises indicates that minor problems will occur.

There is not much on this equipment that can actually be repaired in the field. Major systems of the SIUs are designed as modules that are interchangeable between units. This means that data collection priorities may have to be assigned to the various units and the lowest priority unit cannibalized to maintain the more important units. One note of caution: If the tanks or electronics units of a SIU are switched, recalibrating the tank will be necessary. It is very important that modules are trackable if they are switched between units to ensure that the data are properly analyzed after the cruise.

Do not power up the units if they are cold soaked. It is best to activate the systems at a mild temperature (~15°C) and leave them on while the temperature drops (see *Instrumentation Operation*). This will avoid component failure from thermal shock. This problem is especially chronic with the ultrasonic transducer modules, which will not tolerate start-up after cold soak.

If the washer fluid does not pump after you service the camera unit, pull the back off and check the supply hose and quick disconnects. If fogging occurs on the inside of the camera window, the interior of the CU housing is wet and needs drying. This also indicates that the chloride desiccant is saturated and needs to be dried. The back of the CU housing should be removed and the interior dried with a fan. Replace the dried desiccant and reassemble, taking care not to kink the fluid supply hose in the process.

Because of the vibration and impacts experienced by the equipment, connections may become loose and need retightening. Whenever doing routine maintenance, check all connectors for tightness. If the VCR tape images are not steady, the VCR may need additional isolation. More foam between the unit and the CEU shelf should alleviate this problem.

Proper grounding is also important for good operation. Improper grounding of the equipment can lead to serious problems, especially with low-voltage data acquisition systems. Grounding should not be a problem, but it should be checked. For insurance, installation of an isolation transformer between ship's line and the equipment is recommended. Most other problems that may be encountered with the equipment require either tools or expertise that would not be available in the field, especially aboard ship.

EXTERNAL ANALOG HOOKUPS

Although not originally designed for real-time data analysis, it is possible to monitor certain analog functions of the SIU. To do this, a cable must be attached between the remote terminal and the Campbell data logger interface. Monitoring the following channels will give the following data:

Channel 1: tank depth voltage.

Channel 2: ultrasonic rangefinder analog voltage.

Channel 3: reference voltage for the DAC.

These channels are marked on the screw terminals of the interface. Other functions, such as the temperature, must be specially wired by field personnel. Always check with the ship's captain before planning any real-time monitoring of the SIU.

DATA REDUCTION

As stated, Campbell data loggers were used as the data collection devices for the ship spray–icing measurement units. The data are collected and stored in a memory module that can be removed, downloaded, erased and replaced. Since a variety of data are stored within the module, it is necessary to separate the data into their separate files after they are downloaded (see Campbell Scientific [1991] and SMCOM program for download instructions). The download format used was comma delimited ASCII. The format of these data is specific to the program that recorded them since the first number on a line of data relates to a line number on the Campbell program that stored the data.

The Campbell program that drives the SIU is included in Walsh et al. (1991). This program has three different outputs. First is the spray collection tank data, which, if in spray mode, are recorded once every 12 seconds. Second is the battery voltage, date and temperature measurements, which are taken every 4 hours. Third and last are the icing data, which are collected if the system is in icing mode. It is easier to analyze the data if they are in separate files. To do this, a program, SPLITTER.BAS, was written in Quick Basic. This program is also included in Walsh et al. (1991). Again, it must be noted that this BASIC program is specific to the Campbell program that created the data. Once the data are separated into their own files, serious data analysis can be carried out.

As a final note, remember that if orifice plates are used on the spray intakes, the calculated fluxes will have to be scaled to compensate for the difference in opening. Although this is more important in the analysis of the data, it is good to keep in mind when checking the raw reduced data for accuracy.

RECOMMENDED EQUIPMENT MODIFICATIONS

The equipment described in this report is a second-generation prototype (see Appendix C for specifications). It is not a finished product, and many changes can be made to improve performance and reliability. Everything from instrumentation design to how the equipment is shipped should be examined if money and time become available for redesign work.

The part that most urgently needs examination is the capacitance water gauge system. Initially, this was tested with fresh water and worked fine. Similar systems, available on the open market, claimed to be compatible with seawater. When this setup was used during the *Midgett* cruise, the data became very erratic after the first tank dump. Subsequent testing done at CRREL showed that the salt water had wetted the Teflon wires, thus effectively increasing the capacitive area of the system after drainage. No resolution of this problem has yet been found as equipment is no longer available for testing.

Another area that needs reexamination is equipment mounting. This applies to three specific areas: the electronics enclosure, the deck mounting area and shipping containers. The electronics enclosure of the SIU would benefit from some vibration isolation, perhaps by using rubber grommet mounts between the SIU door and the enclosure or between the back panel and enclosure. A third possibility is to mount a cable spring between the back plane and enclosure. Although there was no damage to the equipment mounted within the enclosure during the cruise, one transducer module was damaged during shipment.

Deck mounting of the SIUs may be improved by the insertion of cable springs between the sacrificial chairs and the mounting flanges. These could also be used when shipping the SIUs. Most problems associated with the SIUs during the *Midgett* cruise could be directly attributable to shipping damage. The batteries were especially susceptible to shipping damage. Careful analysis of the ship and water impact forces will be necessary before any attempt is made to modify the design.

The placement of a layer of vibration isolating material between the sacrificial pad and the camera mount may help to reduce any camera vibration. Although camera vibration was not a problem during the *Midgett* cruise, heavier seas or different ship dynamics may cause a problem. For better isolation, the use of rubber grommets may be necessary. Customizing the shock and vibration isolation system to the specific ship characteristics will be necessary to avoid exacerbating the problem.

The ranging transducer for the icing mode had the highest failure rate of any instrumentation component in the SIU. This was primarily because it is being run outside of its specified temperature operating range. It was used in this application because of its superior resolution. If some resolution can be sacrificed, it would be well worth switching modules to ones with a greater operating temperature range. One alternative currently being investigated is the DCU-7 from Lundahl Instruments, Inc., which has an operating temperature range of –30 to 70°C

with a resolution of 0.76 mm. The number of samples taken per measurement should be increased from 3 to 10 to increase averaging accuracy.

Other improvements may be made to the system to allow easier assembly and installation, but none of these changes are major. As with any design, there is always room for improvement and refinement. The spray–icing units, as currently configured, are not operable in seawater conditions because of the wetting phenomenon associated with the wires of the capacitance water level measurement system. No judgment can currently be made of the ultrasonic ice measurement system owing to incomplete analysis of the data at this date. Some success with a system modeled after the one on the SIUs has been reported in another shipboard application. With the solution of these problems, a viable and otherwise reliable system has been developed for shipboard investigations into the mechanisms and characteristics of shipboard icing in the cold regions of the world.

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Campbell Scientific, Inc. (1991) CR10 Measurement and control module: Operator's manual. Logan, Utah.

Ryerson, C.C. and P.D. Longo (in press) USCGC *Midgett* superstructure icing research cruise: Data collection and instrument performance. USA Cold Regions Research and Engineering Laboratory, CRREL Report.

Walsh, M.R., J.S. Morse, K.V. Knuth and D.J. Lambert (1991) Ship instrumentation manual supplement. USA Cold Regions Research and Engineering Laboratory, Internal Report 1097 (unpublished).

APPENDIX A: SYSTEM STARTUP PROCEDURE

Preliminary checks

Check ambient temperature (must be at least 15°C).
Check air tank connections.
Check wiring connections.

Power-up

Turn on air.
Check tank and regulator pressure (~ 15 mPa and 200 kPa respectively).
Connect batteries to connector bank.
Check operation light on top of SIU (red light = satisfactory voltage).

Program load (cold start)

Connect wye cable to main memory module and data logger.
Connect keypad to open leg of wye.
Check SIU configuration.
Enter: *D7121 for horizontal configuration.
*D7122 for vertical configuration.
*D7123 for vertical configuration and precipitation gauge.
Remove keypad and wye cable.
Connect memory modules to data logger.

Program load (warm start)

Connect keypad and main memory module to data logger as above.
Enter: *0.
Remove keypad and wye cable and reconnect memory modules to data logger.

APPENDIX B: SCHEMATICS

Spray–icing unit

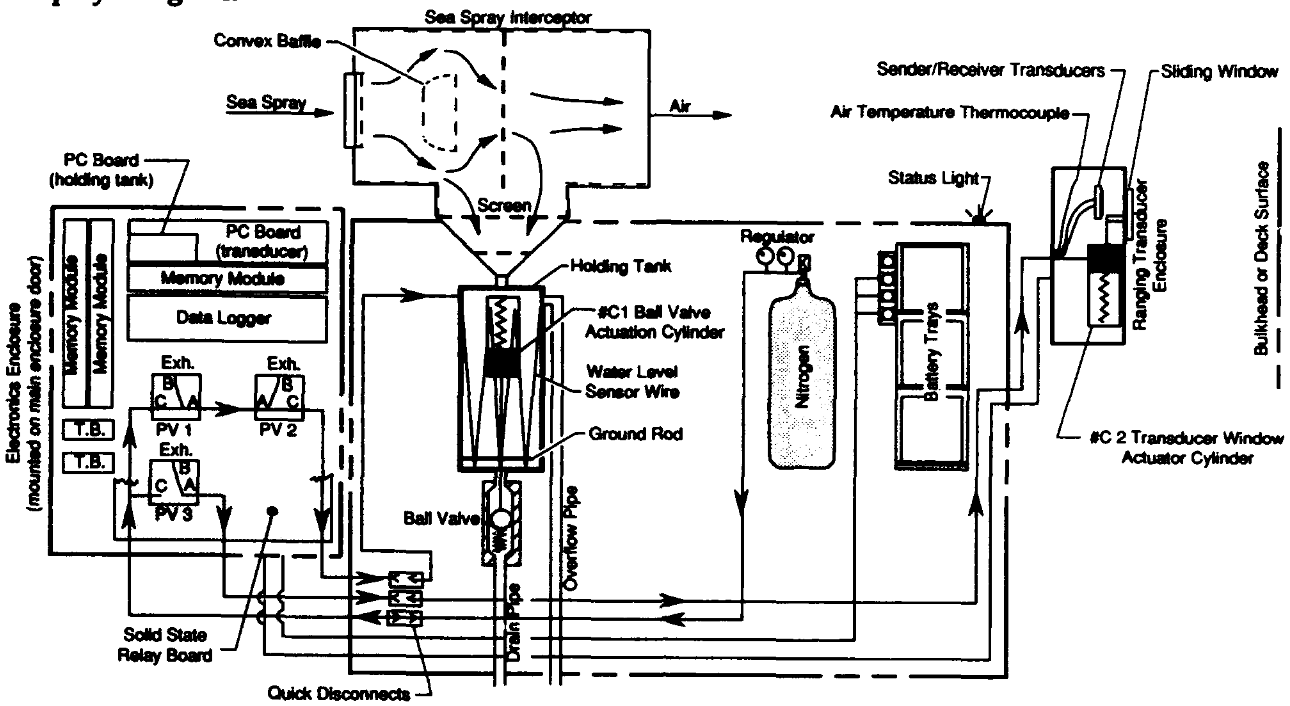

Figure B1: Spray–icing unit layout.

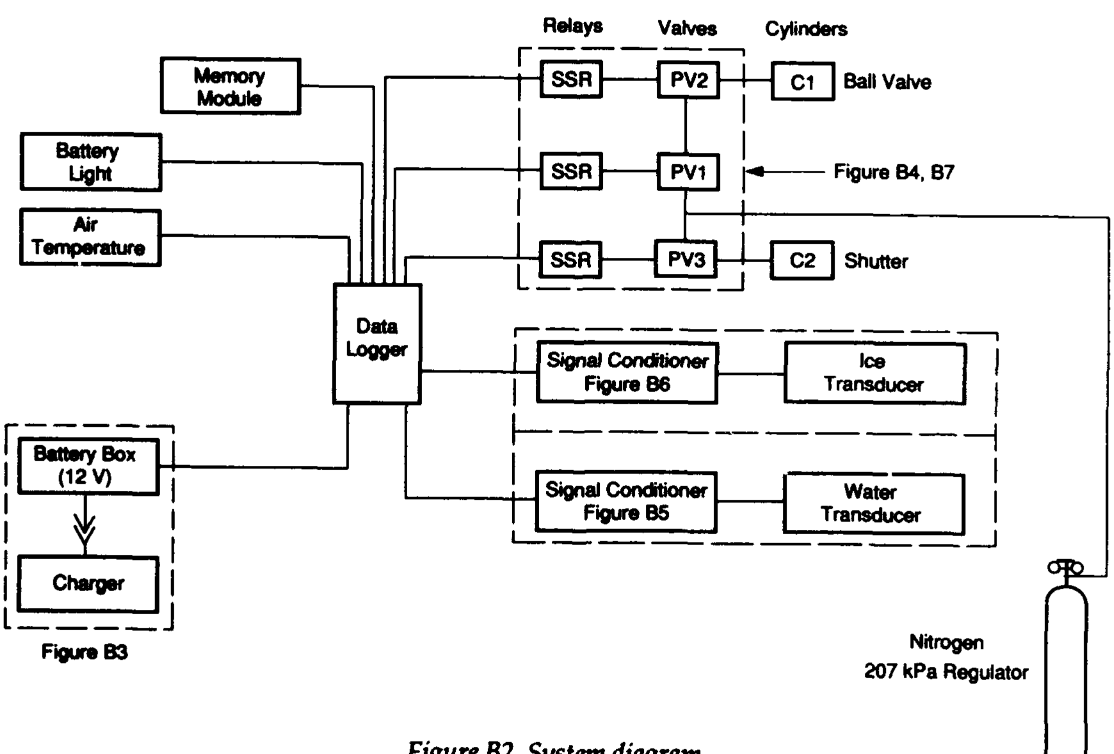

Figure B2. System diagram.

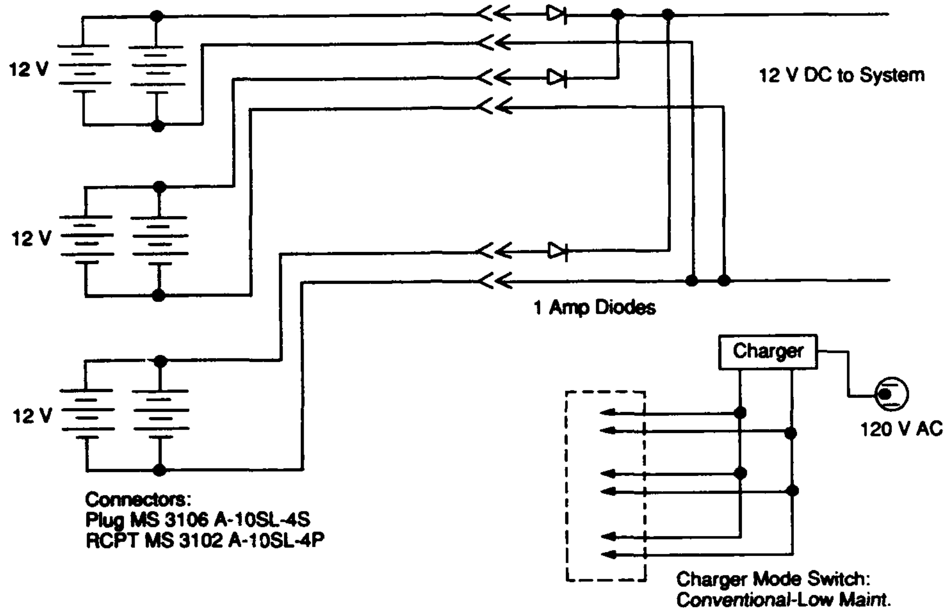

Figure B3. Battery box–charger.

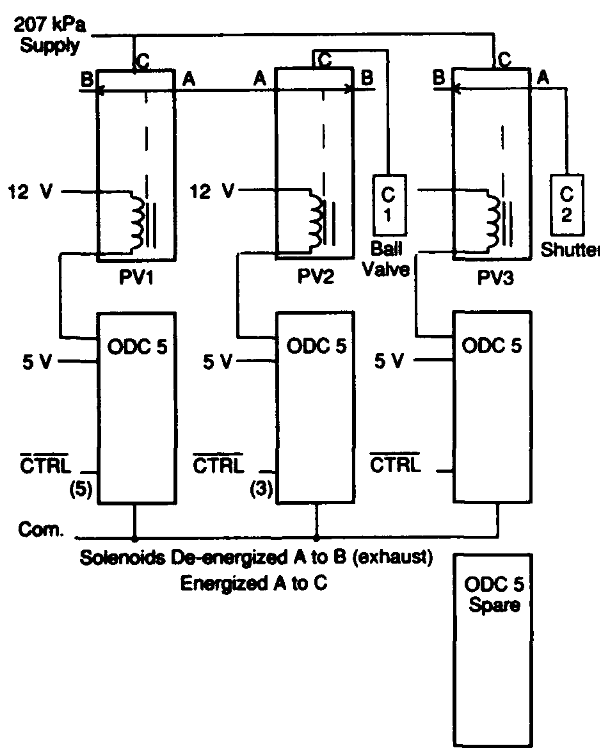

Figure B4. Air solenoids–solid state relays.

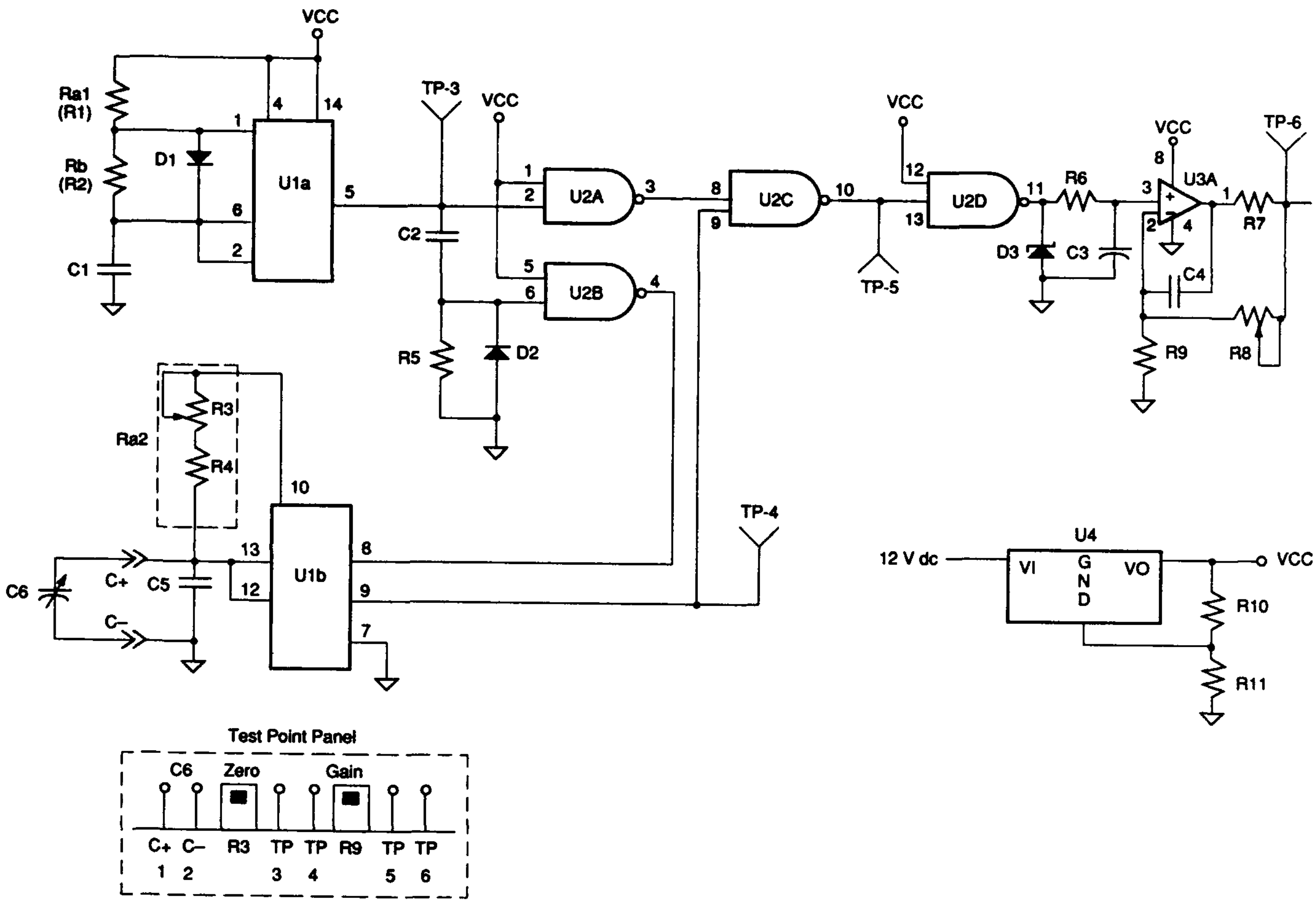

Figure B5. Water tank signal conditioner circuit diagram.

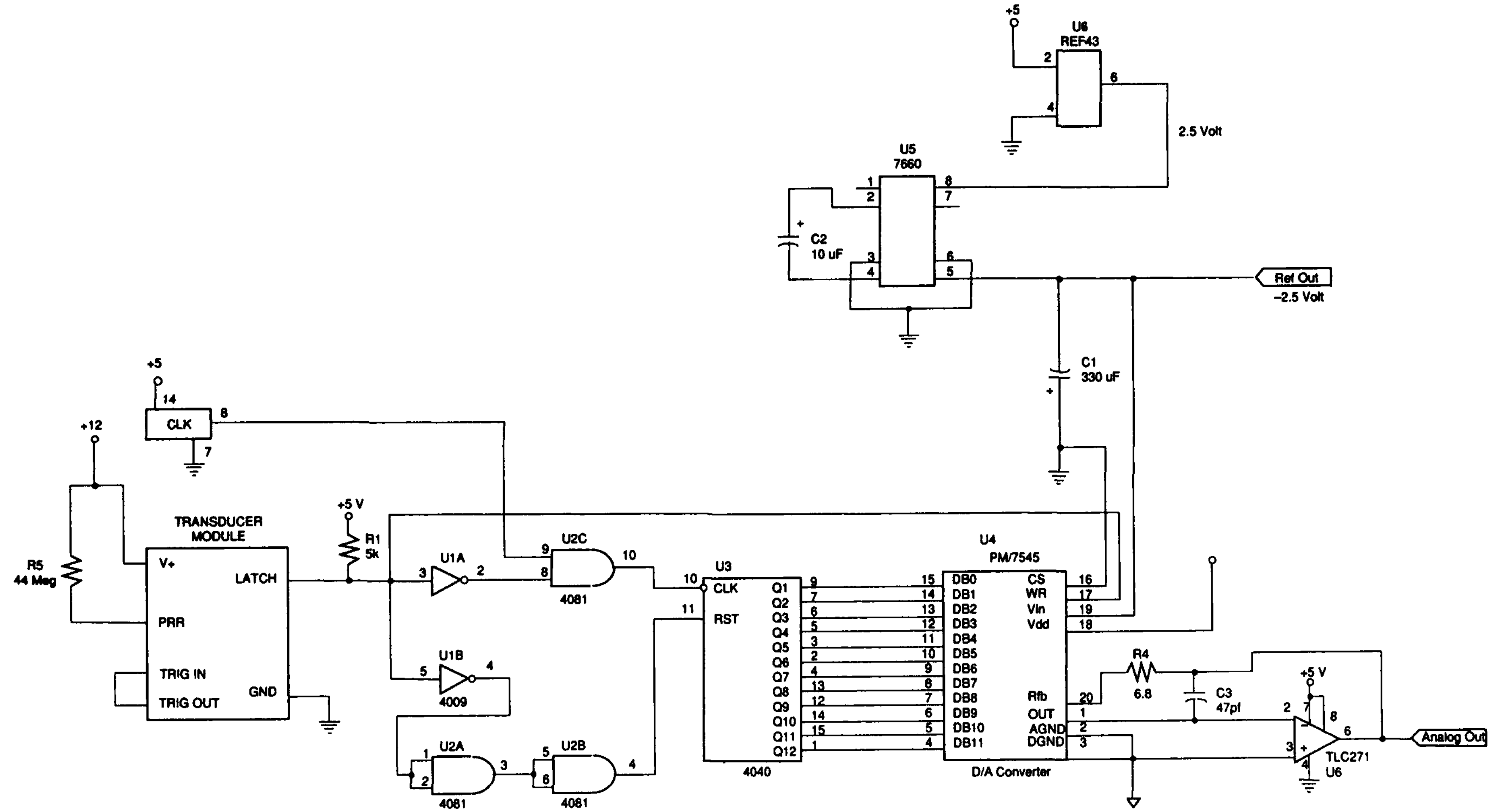

Figure B6. Ultrasonic pulse-width-to-analog-output-circuit diagram.

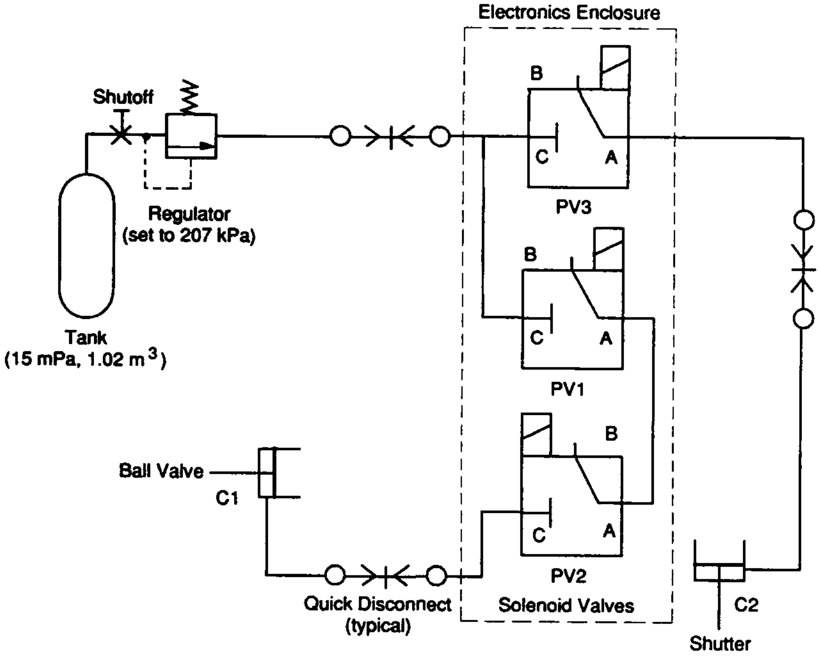

Figure B7. Pneumatic operations.

Table B1. Parts list for water level measuring circuit.

Part code	*Description*
U1	LM556CN
U2	CD4011UBE
U3	LM2904N
U4	ECG964
D1, D2	IN914
D3	IN751A
R1	249 kΩ
R2	3 MΩ
R3	1 MΩ
R4	10 kΩ
R5	10 kΩ
R6	100 kΩ
R7	100 Ω
R8	1 MΩ
R9	150 kΩ
R10	10 kΩ
R11	50 Ω
C1	100 pF NPO
C2	0.001 μF
C3	4.7 μF
C4	0.1 μF
C5	100 pF
C6	Capacitive probe (CRREL)

Video system

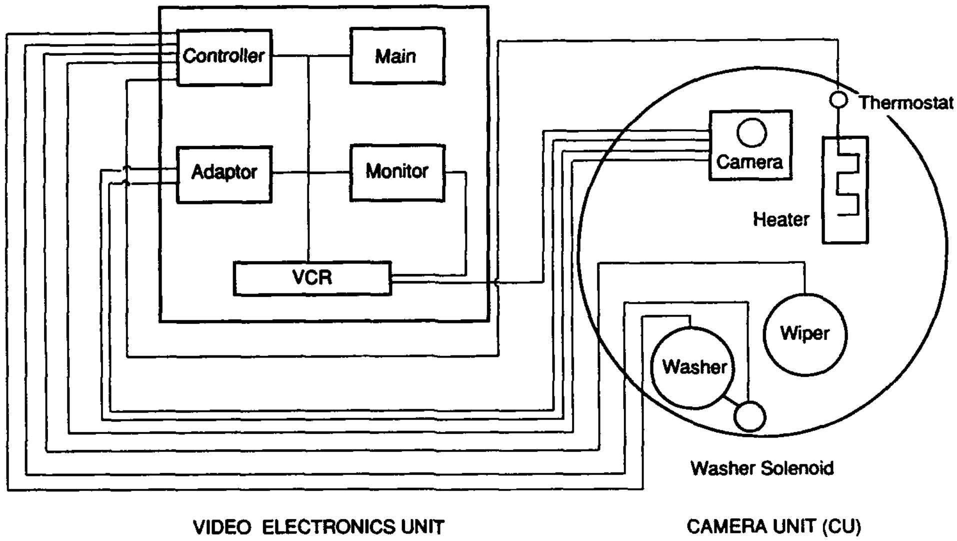

Figure B8. System diagram.

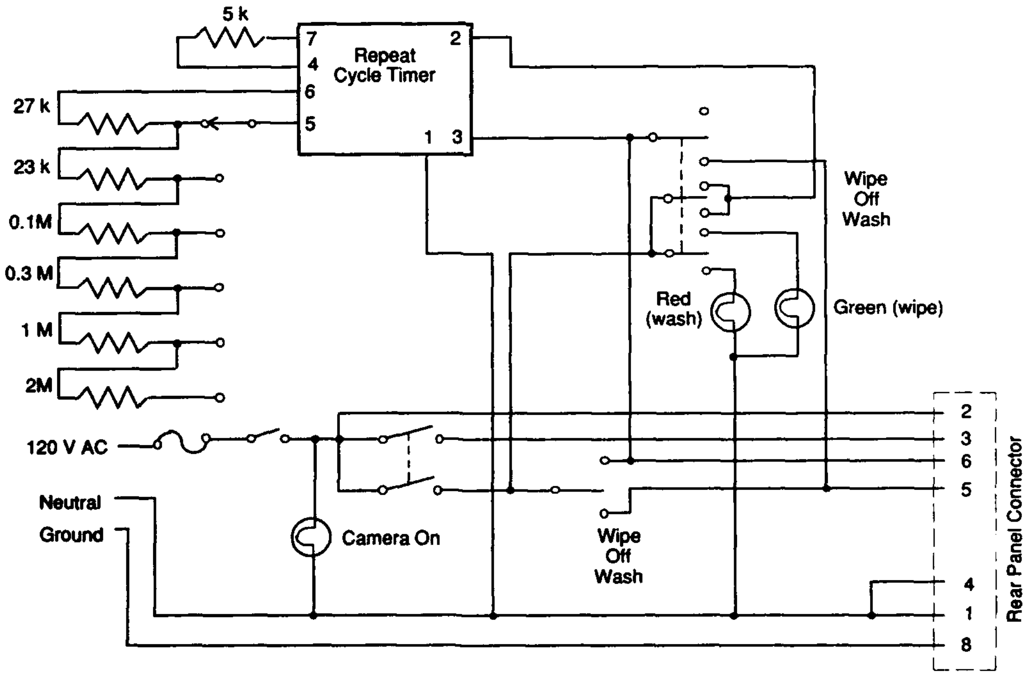

Figure B9. Wiper–washer control.

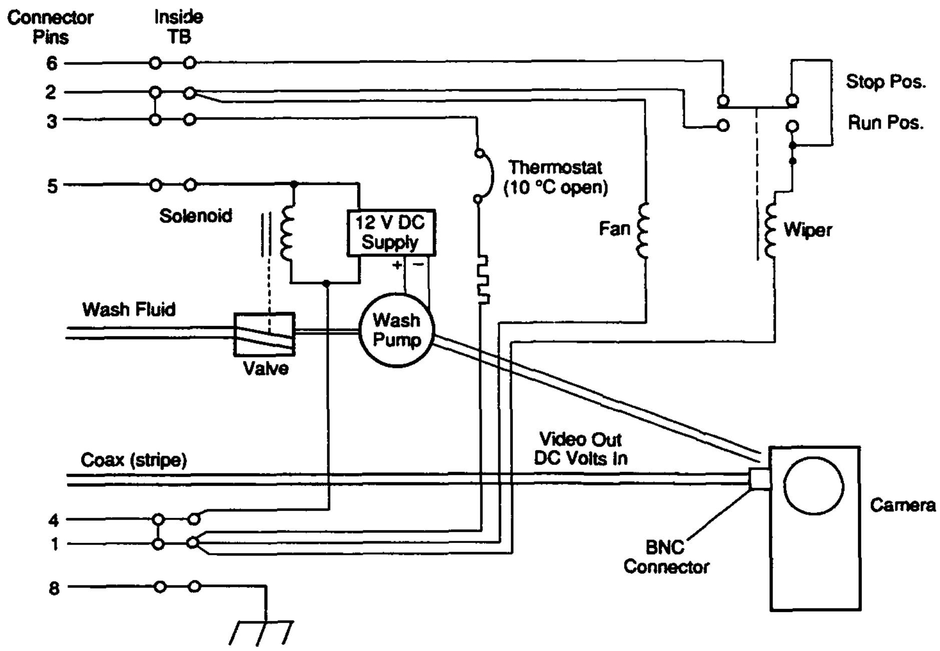

Figure B10. Camera assembly.

Control Box — Camera Housing

Pin	Color	Function
1	W	Neutral
2	R	120V AC
3	K	120V AC
4	K	Neutral
5	B	120V AC (wash)
6	K	120V AC (wipe)
7	N/C	
8	Y and K	Ground

Coax. (stripe) DC in Video Out

Coax. Sync

Figure B11. Camera cable diagram.

Table B2. Wiper delays.

Switch position	*Time between cycles (s)*
1	7
2	13
3	38
4	102
5	332
6	741

APPENDIX C: EQUIPMENT PHYSICAL SPECIFICATIONS

This appendix contains physical specifications that are important when shipping or setting up the ship icing instrumentation. Shipping weights and dimensions, component weights, fully configured weights, and setup clearances are shown on the following sheets. 1 in. = 2.54 cm.

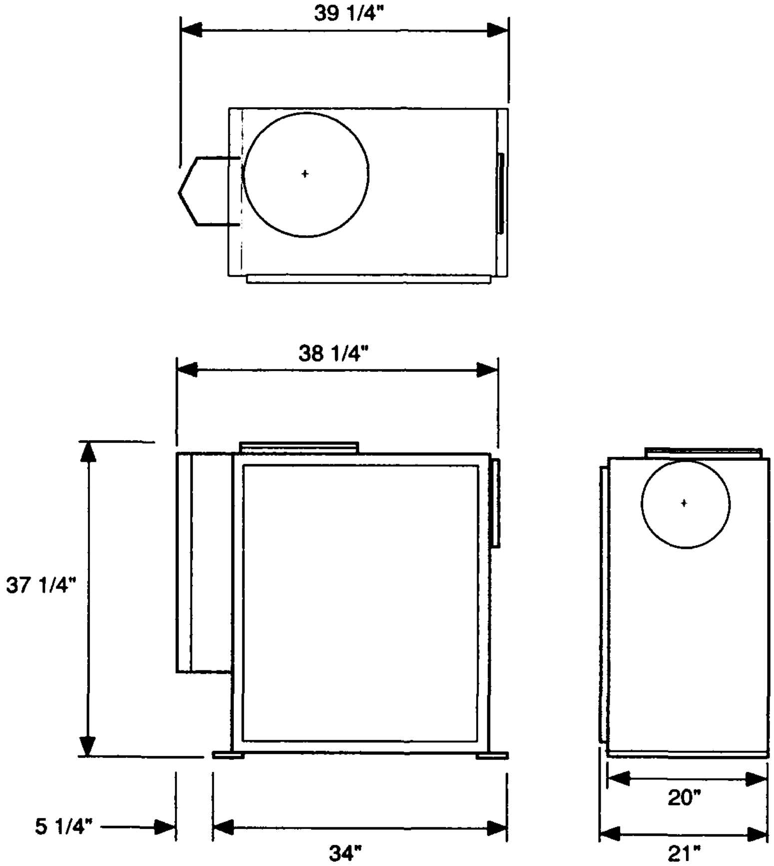

Figure C1. Spray–icing unit in shipping configuration.

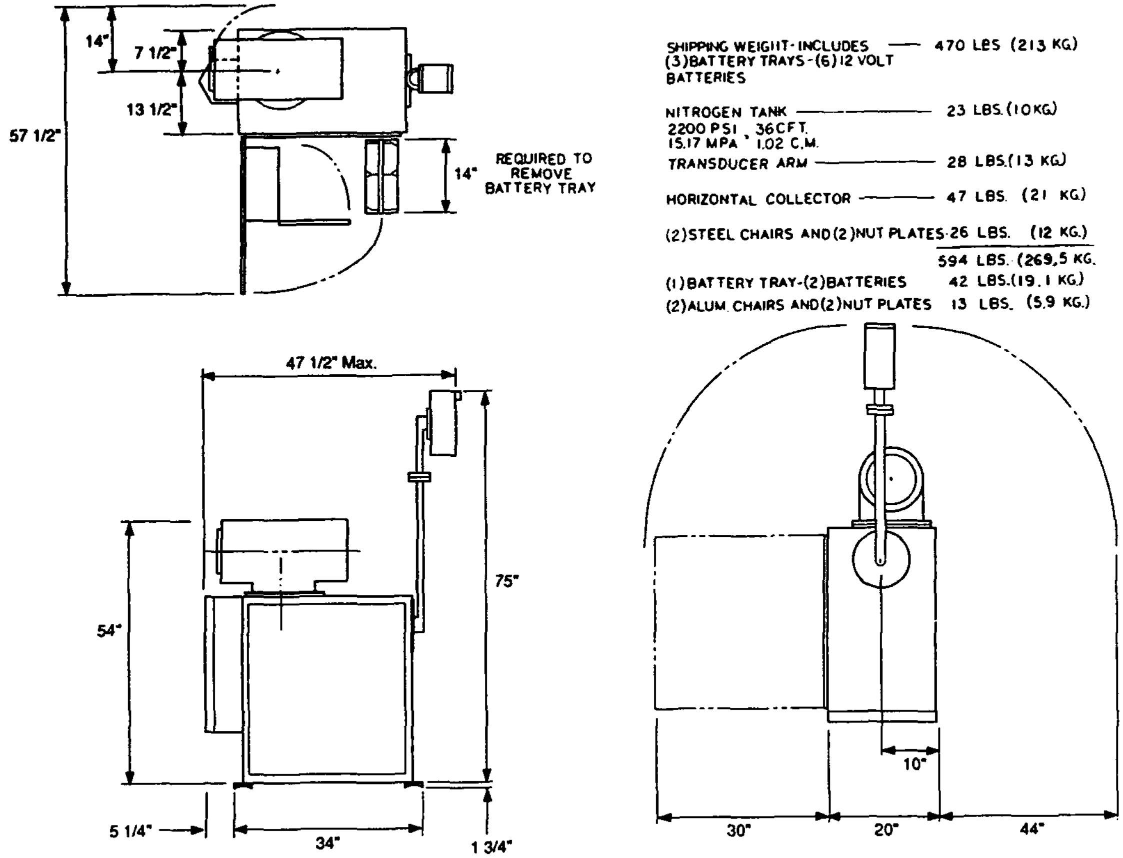

Figure C2. Operational SIU.

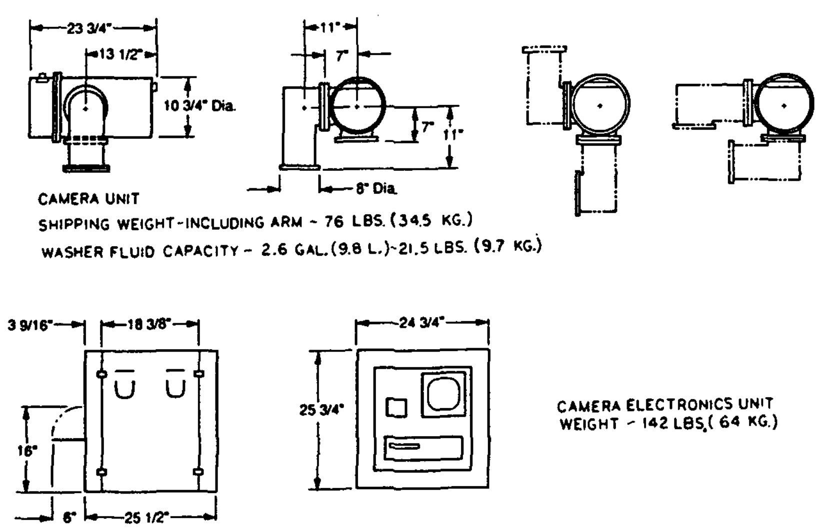

Figure C3. Camera system.

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13. ABSTRACT (*Maximum 200 words*)

To gather empirical data on ship superstructure icing upon which to base and verify a computer model that can be used to predict icing events, the U.S. Army Cold Regions Research and Engineering Laboratory was asked by the U.S. Navy David Taylor Ship Research and Development Center to create a prototype system capable of collecting relevant spray and icing data on ship decks during cold-weather cruises. The resulting ship icing instrumentation can be divided into two parts: a video system to obtain a visual record of spray and icing and several stand-alone instrumented units to obtain quantitative data. The units are capable of measuring liquid water content of spray fluxes in either the horizontal or vertical directions, measuring ice accretion in either direction, and monitoring several other parameters such as temperature and power level. Problems associated with salt water rendered most of the spray data collected during a cruise aboard the USCGC *Midgett* unusable. Some problems with surface roughness may have degraded the ice thickness data. Otherwise, the equipment worked quite well. Further work on using a capacitance gauge to measure salt water levels needs to be conducted before the equipment is redeployed at sea.

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Flux	Instrument design	Spray

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